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NATO-CCMS Pilot Study on Disposal of
Hazardous Wastes. Project: Thermal Treatment
Project Leader: Federal Republic of Germany

NATO Committee on the Challenges of
Modern Society, Brussels (Belgium)

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The report focuses on the incineration of hazardous waste in the participating countries -- The situation in general; details of hazardous waste incineration, co-incineration of hazardous wastes with domestic refuse, hazardous waste as a fuel substitute in the cement manufacturing industry, incineration of selected wastes (PCB, mineral oil wastes), incineration of hazardous wastes at sea, research and development, and conclusions and recommendations of the study.

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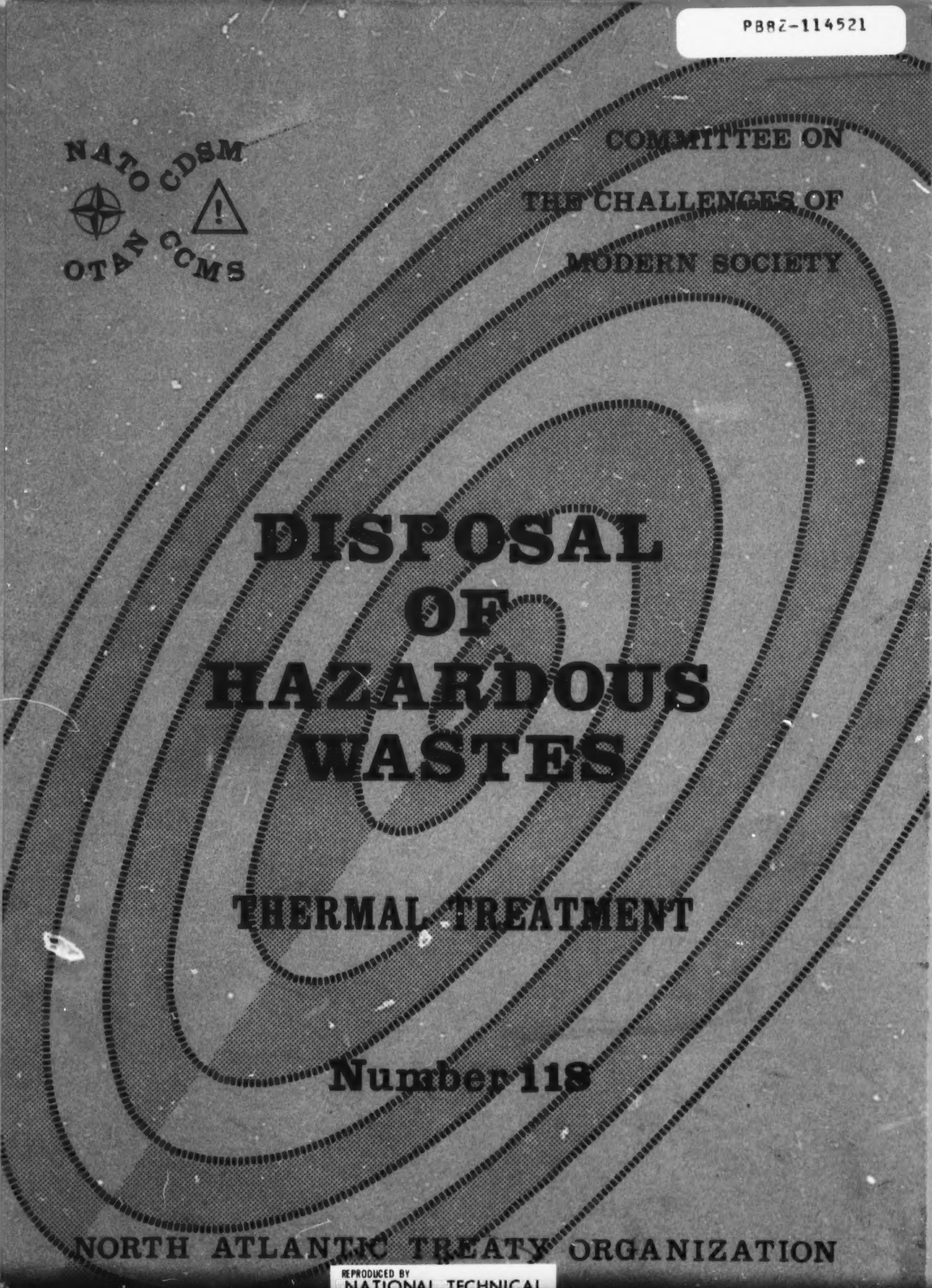

NATO CDSM
OTAN CCMS

COMMITTEE ON
THE CHALLENGES OF
MODERN SOCIETY

DISPOSAL OF HAZARDOUS WASTES

THERMAL TREATMENT

Number 118

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NATO CCMS Pilot Study "Disposal of Hazardous Wastes"

Project: Thermal Treatment

Project Leader: Federal Republic of Germany

Final Report

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1. Introduction

In line with the increase in the demands of consumers and with the consequent growth in industry, the problems of hazardous wastes have increased in recent decades. At the same time, however, the view has become accepted that efforts to manage these wastes should include prevention or reduction of these wastes or recycling them in production processes. Nevertheless, whatever recycling endeavours may be made, there will always remain a certain proportion of hazardous wastes which will have to be converted by means of appropriate methods of treatment into a form in which they can be finally deposited without detriment to the environment. This problem is not restricted to any particular country but rather manifests itself wherever a high level of industrial development has been reached.

The value of thermal treatment of hazardous wastes must be considered in the light of an increased awareness of environmental protection (manifested in corresponding environmental protection legislation) and the compulsion to use energy and raw materials economically. Thus, even in Phase I of the NATO-CCMS Pilot Study "Hazardous Waste Disposal", the recommendation was made that for wastes which could not be otherwise used but could safely be incinerated, incineration with heat recovery should be aimed at as an alternative method of treatment. This recommendation rests on the conviction that

- certain toxic or damaging contaminants can be converted into harmless compounds by oxidation in the incineration process,
- the problem of the shortage of landfill space is alleviated by the reduction in the volume of wastes associated with incineration,
- the risks associated with landfill deposition (groundwater contamination, spontaneous ignition of the waste, gaseous emissions from the landfill) can be avoided by incineration,

- the heat content of the waste can be utilized.

Both traditional incineration on land and, with some reservation, incineration at sea were regarded as appropriate methods by the participating countries.

Having stated the desirable characteristics of incineration, it should be kept in mind that
- emissions from incineration have to be subject to control
- effluents may arise for disposal
- the residues themselves may sometimes require special treatment.

This makes incineration a more expensive disposal route ; and however desirable incineration may be as a waste diposal option, in a freely operating market the most economic disposal route will usually be selected by taking into account the economic and technical aspects of all other possibilities.

It was not possible to take into account all aspects of the disposal of hazardous wastes in Phase I of the NATO-CCMS Pilot Study on Hazardous Wastes. A resolution was therefore passed at the plenary session in Brussels on the 18th/19th of October 1977 to extend the project up to 1980 in a second phase with the following subprojects:

- Thermal treatment
- Biological, chemical and physical treatment
- Wastes from the metal finishing industry
- Landfill disposal research.

The Federal Republic of Germany assumed the leadership of the subproject "Thermal Treatment".

Before the commencement of the subproject the objections, scope and means were formulated as follows:

Objections

The subproject aims at a description of available and prospective techniques of thermal treatment applicable to hazardous wastes and will attempt a comparative assessment of different techniques with regard to different classes of wastes. The assessment shall include treatment schemes for hazardous wastes alone, co-treatment of hazardous and non-hazardous wastes, and utilization of hazardous wastes as raw materials and/or supplementary fuels in thermal industrial processes. It shall comprise land-based operations as well as incineration at sea. The analysis of all available information shall then indicate the options to be considered within an overall hazardous waste management scheme.

To meet these objections, the participating countries were asked to supply information on the state-of-the-art of thermal treatment techniques in each country including

- pretreatment of wastes
- thermal processing details
- treatment of residuals (solid, liquid, gaseous)
- possible usage being made of treatment products
- relevant technical standards and guidelines
- technical problems, e.g. adverse effects and their causes
- operational hazards.

It was agreed, however, not to attempt to make a compilation of existing thermal treatment capacities, and the task was limited to the description of representative examples of technical and operational details of selected facilities from each member country.

Information was sought on the types of plants used for particular kinds of waste and the basis on which certain wastes were excluded. Indications on the development of new technologies were asked for and, in particular, the identification of specific areas where improvements in the existing technology could be made.

In Phase I of the NATO-CCMS Project "Hazardous Wastes" it proved useful to collect the basic information required for the presentation of the current state of waste treatment by means of a questionnaire, and two questionnaires (A and B) were formulated for the implementation of the subproject "Thermal Treatment" as follows:

A General Questionnaire

B Questionnaire on Thermal Treatment Plants for Hazardous Wastes

Specimens of both questionnaires are given in Appendices I and II.

Questionnaire A posed general questions concerning the treatment of hazardous wastes in each country and sought an overview of all the relevant factors including, for example, research and development, organization and controls.

Questionnaire B, on the other hand, concentrated on individual thermal treatment plants and was oriented therefore towards the operators of particular plants. It was assumed that up to 5 plants would be selected per participating country either to show the latest techniques or, as pilot/experimental plants, to illustrate possible trends in future development.

Both questionnaires were sent to all participating countries in March 1978.

By the deadline for the present report (March 1st, 1980) replies had been received from the following countries and were included in the evaluation:

- Canada
- France
- Germany, Federal Republic of
- Great Britain
- Netherlands
- Norway
- United States of America

If there were relevant data available from other NATO member countries, these were also taken into consideration.

2. Incineration of hazardous wastes in the participating countries - the situation in general

It was agreed during the early stages of the subproject that "thermal treatment" would be restricted to incineration only. This is a highly developed technique which is tailored in each case to meet the special requirements of the particular user. Other thermal processes, such as pyrolysis, are still at an early stage of development. It will only be possible to assess their application on a large commercial scale in the treatment of hazardous wastes with certainty in not less than 2 to 3 years. Current research and development projects, however, permit the supposition that new methods such as these will supplement incineration for certain materials.

2.1 Type and volume of incinerated wastes

In order to obtain a general picture of the type and volume of wastes, Question 1 presented a list of wastes which can be treated thermally. Respondents were asked to specify the volume of each waste generated and the portion which is treated thermally.

Difficulties arose even in the selection and definition of the types of waste. In Phase I of the project it emerged that lists of hazardous wastes are generally still in the preparatory stage in the participating countries. Although the particular methods used to draw up such lists vary from country to country, there is nevertheless a considerable measure of international agreement on which substances should be regarded as hazardous from the point of view of disposal. Where these substances are amenable to thermal treatment, they have been included in Question 1 of the general questionnaire. A further basis for the classification of types of waste was the Waste Catalogue published in the Federal Republic of Germany in autumn 1977 by the Laender Joint Committee on Waste and the Federal Ministry of the Interior.

It was left open to the participating countries to group several wastes together or to further subdivide individual types of waste, as well as to make additions to the table.

When the completed questionnaires were being processed it became clear that, with regard to the thermal treatment of hazardous wastes, insufficient information was available for many of the wastes listed. The United States of America, for the time being, did not see itself in a position to answer Question 1. This was due to the fact that currently only a few of the States of the U.S.A. have issued regulations on hazardous wastes which provide for monitoring of the incineration of these wastes. This meant that information concerning the methods currently being used was very scanty. It was, however, stated that increasing implementation of the "Hazardous Wastes" section of the "Resource Conservation and Recovery Act" of 1976 would in future permit precise details of the type and volume of wastes and methods of treatment to be given. Great Britain answered the question concerning the volume of wastes in great detail. It also introduced new designations for individual types of waste and provided explanatory notes in the form of extensive remarks. Norway and Holland provided exact and comprehensive details, whereas the

Federal Republic of Germany's replies were, in some respects, incomplete. It is to be expected that the evaluation of future statistical inquiries will yield further progress.

In general, the make-up and validity of the replies varied too greatly for a detailed presentation in the form of a comparative table to be made. The information given in Table 1 should therefore be critically assessed.

Table 1 Survey of the occurence of hazardous wastes in individual countries

Country	Total volume of waste (t/a) 1)	Portion incinerated (t/a)	(%)
France	2.000.000	400.000 2)	20
Germany	3.500.000	540.000 3)	16
Great Britain	3.000.000	150-200.000 4)	5-6, 6
Netherlands 5)	420.000	210.000	50
Norway	200.000	50.000 6)	25
United States	35.000.000	1.960.000	5, 6 7)

Remarks:

1) including waste oils etc.

2) not including on-site incineration

3) not including appr. 320.000 t/a which are co-incinerated in household waste incineration plants

4) not including in-house (on-site) incineration of about 600.000 t/a in 73 in-house plants of which substantially more than 50 % is accounted for by the oil refineries and the largest chemical manufacturers

5) including waste oil and substitute fuel
including incineration at sea
excluding biological sludges
excluding on-site treatment

6) including 50 % of waste oil used as fuel substitute

7) another 9, 7 % are uncontrolled incineration (all figures being estimated)

2.2 Organization of incineration plants

Question 2 of the general questionnaire originally concerned the number of existing hazardous waste incineration plants, their organization (public, private or joint ownership and operation) and their capacity.

The replies to this question varied considerably. One country said that some information was available on 5 plants but that it was known that several industrial firms operated their own plants for the disposal of their wastes. The number of such plants as well as the type and volume of wastes treated in them were, however, unknown. Another country specified only the number of publicly operated incineration plants. This country was of the opinion that industrially operated plants should not be included in a survey; on the one hand because it considered that only those substances should be designated as wastes which leave the industrial site (the incineration plant was thus regarded virtually as a link in the production chain) and, on the other hand it was said to be extremely difficult to obtain information on such plants. The pilot study working group, however, was strongly of the opinion that such plants should be taken into consideration, although it would be difficult to obtain precise figures. Therefore due to lack of data in this area, no detailed information was available on all plant capacities. However, it is likely that the capacity of plants for the incineration of hazardous wastes (both internal industrial plants and plants serving a number of firms) is between 25.000 and 90.000 t/a. Details will be found in Section 3.2. The organizational aspect was also discussed in considerable detail.

2.2.1 General remarks on internal industrial and supra regional incineration plants[1]

The question of the organization of incineration plants must be seen from different angles. It is not generally possible to dispose of hazardous wastes jointly with domestic refuse. Since special demands are made on the treatment methods used, its acceptance by such plants is often ruled out by those responsible for disposal. The producers of the special wastes thus necessarily remain responsible for disposal.

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[1] Gromotka, H.: Industrieabfall- und Sondermüllverbrennung in: U - das technische Umweltmagazin, März 1978

For large firms this may be less of a problem since, for technical and economic reasons, they are often in a position (particularly in view of the volume of waste) to install their own plants for incineration or other treatment. The situation is more difficult for medium-size and small firms which usually do not have sufficient resources of their own to dispose of their waste properly at tolerable cost. The illicit disposal of hazardous wastes , which has occurred in some countries in the past, was due in particular to the fact that these operators were not in a position to dispose of these waste substances properly and consequently availed themselves of the services of dubious disposal agents. For the small and medium-size firm, therefore, solutions must be found at a level above that of the individual firm. This has led, over recent years, to the establishment in some countries of companies supported either completely by public funds, jointly by various industrial operations with state participation, or completely by private funds.

Whether the plant is an internal installation or a unit serving many firms has considerable effects on the technical arrangements within the incineration plants. Although the range of wastes in internal industrial incineration plants is frequently broader than the range of products, nevertheless the wastes and their properties, such as volume, state of aggregation, calorific value, composition, incineration behaviour etc. are largely known when the wastes arrive for incineration. In addition, the rate at which individual substances are generated can be determined over a period of time. It is possible to vary the handling of the waste: it can be analysed and intermediately stored or, if required, processed or pretreated.

In other words: the so-called logistics of waste are well organized in internal industrial incineration plants. The plants are also designed accordingly. The individual components have only the required reserve capacity. The measurement and control devices as well as the overall automation of the plant can be more simply arranged. Any problems of supply and disposal (water, power, steam, chemicals) and, not least, staff problems are more easily solved. Certain organizational processes and tasks such as transport and use of workshops and laboratories can be more rationally, simply and economically arranged within an industrial operation.

The situation with regard to hazardous waste incineration plants serving a number of firms is very different, with problems arising at the stage of selecting the location, taking into account refusals by local authorities and civil action group campaigns (see also Section 3. 4. 3). The approval procedure is often long and difficult. The data relating to waste on which the planning and design of the plant are based later rarely prove to be accurate. Under certain circumstances the range of wastes changes more rapidly and is to some extent also unpredictable due to the commissioning and closure of plants in various areas of industry. This means that even at the planning stage of a special waste incineration plant the necessary flexibility must be included to accommodate a possible future change in the composition of the waste.

Wastes of unknown origin are frequently delivered for incineration which cannot take place without preliminary analysis and a knowledge of their composition. This means, however, that the plant must be designed with a certain safe reserve in order to remain operational when faced with unavoidable load alternations or fluctuations.

Other factors taken into account in siting supra regional plants include location in relation to services of waste generation and equalization of transportation costs as well as the distance to a user of the power which can be generated.

Besides the more technical arrangements there may occur some disadvantages in connection with disposal by contractors:[1] the waste generator may have to disclose details of the waste analysis to outsiders and he often remains responsible for the waste if, owing to operating difficulties, the wastes cannot be accepted for processing.

2.2.2 Supra regional incineration plants - the situation in individual countries

In Canada, there are two regional incineration facilities with a possible third in the planning stage. All are privately owned and financed. Licensing of these facilities is the responsibility of the government of the provinces in which the incinerators are located.

Table 2 shows all incineration plants for hazardous wastes in Germany which are available. Internal industrial plants, serving only the particular industrial operation, are excluded from this overview.

There is one supra regional incineration plant in the planning stage (Biebesheim II) which should go into operation in 1981. No other detailed planning is known so far.

Whilst the first three facilities are operated privately, all the others are run by companies, the shares of which are held by various industrial companies and local government.

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[1] Dartoy, J.: The incineration of hazardous waste, Process-Engineering Group 191-4605/JD/dm, Battelle - Geneva, December 1979

The plants in France for hazardous waste incineration are listed in Table 3. They have a supra regional function. However, only two plants have the appropriate facilities which enable them to incinerate organo halides in significant quantities under environmentally acceptable conditions. Public funds (loans, subsidies) have been allocated since the first plants went into operation. In order to encourage the treatment of industrial wastes in these centers subsidies are granted by the "Agences financières de bassin" which may vary from 20 to 45% of the treatment costs. The financial resources of this organzisation originate from levies paid by industrial waste generators.

There are no proposals in the United Kingdom for the construction of supra regional incineration plants as part of a centrally controlled waste treatment strategy. Private waste disposal contractors who operate thermal treatment plants make their own commercial judgements on the location of such installations and the economic viability without the backing of public money but initially subject to planning permission being granted by the district council or by the Secretary of State for the Environment as a successful appeal against refusal by the local authority. A survey of hazardous waste incinerators is given in Table 3a.

Five years ago Norway considered the installation of national incinerator for hazardous wastes, but for various reasons this had to be reconsidered. A cement company is currently interested in obtaining low cost energy by incineration of hazardous wastes in a cement kiln. A governmental grant of about 1.3 Mio N.K.r. to run the necessary tests will be made available. Limitations of harmful emissions into the atmosphere will be imposed into the operation. A more stringent limitation on the amount of halogenated wastes being accepted by the plant may be necessary due to the Norwegian cement manufacturing standard specifications.

The admittedly incomplete picture of the situation in the member countries shows that currently predominantly internal industrial incineration plants

Table 2 Supra regional hazardous waste incineration plants in Germany

Location	Start up	Plant capacity	Flue gas cleaning	Remarks
GMU Bochum	1977 1)	120 GJ/h	Electrostatic filter + scrubber	Solid and fluid wastes are burnt of which up to 10-15 % are halogenated
Schering Bergkamen	1969	24 GJ/h	Scrubber	also chlorinated hydrocarbons are burnt
AVG Hamburg	1968	60.000 t/a	Electrostatic filter	a dry cleaning system (Sorption) is planned to seperate the gaseous hazardous compounds
Biebesheim I (HIM)	1970	30.000 t/a	Electrostatic filter	Scrubber planned for the near future. Then chlorinated hydrocarbons may be burnt in addition
Ebenhausen (GSB)	1976	40.000 t/a 100 GJ/h	Electrostatic filter + scrubber	Also solid, pasty and fluid chlorinated hydrocarbons are burnt. Doubling of capacity possible by adding a second unit
Schwabach (SMM)	1972	14.000 t/a	Electrostatic filter	In addition to incineration extensive facilities for physical and chemical treatment (similar to Ebenhausen)
Schweinfurt (GSB)	1975	40 GJ/h	Electrostatic filter	Reconstruction of an older plant which went into operation in 1969
Biebesheim II (HIM)	1981	50.,000 t/a 63 GJ/h	see remarks	Wet scrubbing system with lined up drying reactor

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1) Although this plant was licensed till 1981 it was closed down in the beginning of 1979 because of lacking amount of wastes delivered to the plant

Table 3 Centres d'Incinération en France

Nom du centre	Capacité 1) (T/an)	Propriétaire	Adresse
Baisieux	10.000 (5.000) 2)	Impérator	Rue de Breuze 59 000 Baisieux Tél. (20) 56-76-68
Brioude	4.000	Speichim	Rue Emile Barret 43 000 Brioude Tél. (71) 50-13-34/76
Courrières	80.000 (60.000)	Houillères du Bassin du Nord et du Pas-de-Calais	Centrale Thermique de 62 710 Courrières Tél. (21) 20-24-04
Hombourg	5.000 (3.000)	Pec Engineering	B.P. 43 68 170 Rixheim
Lillebonne	60.000 (40.000)	Matthys	Z.I. avenue de Port Jérome 76 170 Lillebonne
Lillers	15.000 (13.000)	Pec Engineering	B.P. 4 62 190 Lillers Tél. (21) 02-28-14
Limay	15.000	Sarp Industries	B.P. 10 78 250 Limay Tél. (1) 092-04-77
Mitry-Compans	18.000 (10.000)	Gerép	Rue Jacquard Z.I. de Mitry-Compans 77 290 Mitry-Compans
Pauillac	12.000	N.I.C.	33 000 Merignac Tél. (56) 47-12-23
Rognac	60.000 (35.000)	Solamat	Montée des Pins 13 340 Rognac Tél. (91) 87-06-72
St. Maurice l'Exil	18.000 (13.000)	Pec Engineering	B.P. 24 38 790 St.-Maurice-l'Exil Tél. (74) 86-10-83
St. Vulbas	25.000 (13.000)	Plafora	Z.I. de la Plaine de l'Ain 01 150 St. Vulbas s/Lagnieu Tél. (74) 61-03-55
Sandouville	45.000	Semedi	Z.I. Port Autonome du Havre 76 000 Sandouville
Strasbourg	15.000	Spirs	Port Autonome de Strasbourg 67 Tél. (86) 61-40-65

1) Les tonnages incinérés en 1978 sont indiqués entre paranthèses

2) Tonnage incinéré en 1977

Table 3a Contractually available incineration plants in the UK

Address	Nominal incineration capacity (t/a)	Types of waste incinerated
Berridge Incinerators Ltd Wigwam Lane Hucknall Nottinghamshire	8.000	Liquids only, including halogenateds
Effluent Disposal Ltd, Croda Synthetic Chemicals Ltd Four Ashes Wolverhampton Staffordshire	20.000	Oils, oil/water, no halogenateds
Hargreaves Clearwaste Ltd Calder Vale Road Wakefield West Yorkshire	40.000	Liquids only, no halogenateds
Rechem International Ltd Pontyvelin Industrial Estate Panteg Pontypool Gwent	35.000	Liquids and solids, including halogenateds
Rechem International Ltd Roughmute Larbert Stirlingshire	35.000	Liquids and solids, including halogenateds
Rechem International Ltd Charleston Road Hardley Hythe Southhampton Hampshire	35.000	liquids only, including halogenateds
Redland Purle Ltd Oil Sites Road Ellesmere Port Cheshire	20.000	Liquids only, including halogenateds
Redland Purle Ltd Ferry Lane Rainham Essex	13.000	Liquids only, no halogenateds

are being operated. However, the future trends are likely to be towards the construction and operation of supra regional incineration plants. Table 4 lists specific examples of such plants.

Table 4 Specific examples of supra regional hazardous waste incineration plants in individual countries

Country	Location of plant	Operator	Capacity (t/a)
Denmark	Nyborg 1)	Kommune Kemi S/A	80.000
France	St. Vulbas s/Lagnieu	Plafora S. A.	48.000
	Sandouville	Sedibex S. A.	45.000
Great Britain	Southampton	RE-Chem. Int. Ltd.	35.000
	Pontypool	-"-	35.000
	Roughmute	-"-	35.000
Germany	Ebenhausen	Gesellschaft zur Beseitigung von Sondermüll in Bayern	40.000
	Biebesheim (planned 1981)	Hessische Abfallverbrennungs-GmbH	50.000
Netherlands	Rotterdam-Botlek 2)	N. V. Afvalverwerking Rijnmond	28.000
Norway	Oslo, Slemmestad 3)	Norcem A/S	50.000

1) This plant is not included elsewhere in the evaluation

2) Although disposal prices increased in average 50 % in 1980 (details see chapter 3. 4. 2) the company faces serious financial problems and is discussing with the central government the continuation of the incineration activity for chemical waste.

3) Cement kiln incineration, planned for 1981

2.3 Assessment of hazardous waste incineration

In order to sustain our ecological system it is necessary to minimize the negative influence of waste disposal by practical utilization and/or transformation of waste substances within a controlled amount of time into a form where they can be discarded without any damage to the environment.

Incineration, besides recovery, seems to be a viable option. This is backed by a change in motivation, which has been observed recently (e.g. to avoid long term liability of other waste disposal methods). In order to get more detailed information, the participating countries were asked to give their judgement of the incineration of hazardous wastes with regard to:

- volume reduction
- energy use possibilities
- raw material recovery possibilities
- treatment of wastes so that residues can be disposed of without special precautions.

The replies can be summarized as follows:

- Volume reduction: incineration of special wastes is an excellent method of volume reduction which, at a time when the availability of landfill sites is decreasing, is an increasingly significant factor. The incineration of wastes with sufficient calorific values should be the preferred method in laws, administrative regulations and statutes.
- Energy use: in any selection of a technology for waste treatment, energy use is a major factor especially given the tendency of energy prices to continue to rise. As has already been mentioned organic wastes with sufficient calorific value should therefore be disposed of by incineration. It will be necessary to intensify research work in order to investigate the technology and economy of heat recovery from special waste incineration plants.
- Raw material recovery: in the incineration of special wastes the raw material recovery possibilities are very small. It seems feasible on a sizeable scale only with gasification (pyrolysis). The extent of the use of thermal treatment for raw material recovery must be seen in relation to energy recovery and the value of the secondary raw materials.
- Residues: when special wastes are incinerated, residues are produced in the form of slag, fly ash and sludges from flue gas purification. There

is, at present, insufficient knowledge concerning the extent of the toxicity of these residues. Continuous analyses have shown that some incineration residues (e. g. fly ash) must themselves still be classified as special wastes and deposited on appropriate landfills. 1) The residues should therefore be regarded as hazardous until analyses prove the contrary. If necessary, special treatment methods (e. g. fixation) should be used.

An evaluation of the replies indicates that the use of incineration for the treatment of hazardous wastes is seen predominantly from economic points of view. For example, wastes currently are incinerated only if they have a sufficiently high calorific value for incineration. The question remains whether incineration should not be increasingly assessed in the light of ecological criteria, i. e. seen as a technical means of degrading hazardous wastes or their chemical compounds into less hazardous or non-hazardous compounds within a controlled period of time by the effect of high temperatures, and whether purely economic aspects (e. g. costs arising for the use of additional auxiliary fuel) should not be considered of lesser importance.

2.4 Legal conditions for incineration

The wording of the relevant question asked on the questionnaire was: "What sort of organizational conditions exist in your country for the operation of thermal treatment plants for hazardous and special wastes?"

In the United States of America the responsibility for hazardous waste incineration plants rested whith the individual states until 198o. Most states, however, had no special regulations covering these special incineration plants.

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1) Although some member countries would not like to exaggerate this. By incineration, many of the toxic substances are destroyed (e. g. chlorines, hydrocarbons). Still the residues may contain some hazardous components as heavy metals but these will (mostly) be oxidized and therefore transformed into a less hazardous form.

Uniform federal regulations covering incineration plants for hazardous wastes were published in 198o. These standards cover requirements for site location and design, operating methods, emission limits, control of residues contingency plans, personnel training, financial responsibility, recordkeeping, reporting, monitoring, inspection, and others.

The standards for hazardous waste incinerators prescribe conditions for destruction of the waste introduced and for control of the resulting emissions. Thus, these rules include specifications on destruction and removal, efficiency and automatic feed cutoffs. Trial burns are required for incinerators burning waste of a type which has not previously been burnt in similar incinerators. Additionally, an emission standard for particulates is given.

Limiting standards mentioned above include

- 99,99 per cent destruction and removal efficiency
- O,O8 grains per dry standard cubic foot stack concentration limit for particulates (= 180 mg/m^3)
- monitoring requirements

Because it is impossible to change waste disposal practice overnight (this is estimated to take up to five years), there will be an interim period during which a facility is subject only to a limited set of requirements pending issuance of a full permit.

In Norway incineration plants for hazardous wastes are approved on a case-by-case basis. Emission limits, e.g. for particulates, CO, SO_2, HCl or lower limits for incineration temperature, residence time of flue gases in the reactor and stack height are set.

In Canada the responsibility for incineration plants currently resides with the provincial governments.

In Great Britain incineration plants, like all other waste treatment plants and disposal facilities, are subject to licensing by the Waste Disposal Authorities under the Control of Pollution Act of 1974. However, before any new waste treatment or disposal facility can be up and licensed, planning permission must first be obtained from the local planning authority or the Secretary of State for the Environment on successful appeal against initial refusal.

The operation of thermal treatment plants for hazardous and special wastes are subject to the following legislative requirements:

1. Planning permission for the erection of the plant if on a new site. Other planning considerations may arise if on an existing industrial site (unless excluded by application of the General Development Order). Planning is within the province of the District Council.

2. Licensing of the site by the Waste Disposal Authority (the Country Council) under Sections 3 to 11 of the Control of Pollution Act 1974.

3. Health and safety at work matters exercised by the Factory Inspectorate (on behalf of the Health and Safety Executive) under the provisions of the Health and Safety at Work Act 1974 and subsequent regulations.

4. Control by the Water Authority over any liquid discharges from the plant either into a sewer for treatment at a sewage treatment works or for discharge into a watercourse.

5. Notification to the Waste Disposal and Water Authorities of approriate wastes for disposal from the plant under the Deposit of Poisonous Waste Act 1972. This will by superceded by regulations made under Section A of the Control of Pollution Act 1974.

6. Control of atmospheric emissions by HM Alkali and Clean Air Inspectorate where appropriate. Although the atmospheric emissions from in-house incineration plants are also subject to control by HM Alkali and Clean Air Inspectorate, where appropriate, such facilities are not licensable by the Waste Disposal Authority (item 2), being regarded as part of the manufacturing process.

7. The local Environmental Health Officer (District Council), exercising functions under the 1936 Public Health Act.

It should be noted that the Department of the Environment Waste Management Papers on specific hazardous wastes which contain information on arisings, treatment and disposal, also include non statutorily enforceable guidelines on waste disposal and treatment procedures.

With reference to item 6 on the control of atmospheric emissions by HM Alkali and Clean Air Inspectorate, if the chemical incinerator burns waste which is likely to produce HCl or other emissions scheduled under the Alkali Wastes Orders then the incinerator operation becomes a reagistered process. Cn this basis some chemical incinerators are registered and others are not. The same principle would apply to municipal incinerators where the nature of the chemical waste co-incinerated would determine the status of the incinerator with regard to scheduling under the Alkali Act. Such considerations are, however, currently under review.

In France under the law of Juli 19, 1976 referring to plants for environmental protection and the "decrée of application" of September 21st, 1977, the waste treatment plants, and especially the hazardous waste incinerators, are subject to permission of the local authority ("autorisation prêfectorale"). Furthermore, under the law of July 15, 1975 concerning the disposal of wastes and, in particular, article 9 (the "decrée of application" is in prepreparation) hazardous waste treatment facilities will be subject to permission of the central government. It will become obligatory for hazardous waste producers to have the residues treated in a licensed facility which includes thermal treatment, physical/ chemical treatment and the operation of landfill sites).

In Holland the construction and operation of special waste incineration plants are governed by the

- Air Pollution Act
- Chemical Waste Act
- Public Nuisance Act

In the Federal Republic of Germany the construction and operation of plants is approved under a plan approval procedure. The laws which are applied under this procedure and which are of importance from the point of view of environmental protection are the

- Disposal of Wastes Law
- Federal Law for the Prevention of Harmful Effects on the Environment Caused by Air Pollution, Noise, Vibration and Similar Phenomena (Bundes-Immissionsschutzgesetz, BImSchG) together with the relevant statutory instruments
- Technical Instructions for the Maintenance of Air Purity
- Technical Instructions for Protection against Noise
- Water Resources Law in conjunction with the Sewage Rates Law

This comprehensive regulation ensures that the incineration of special wastes cannot cause any shift of emissions from the air into the water or into the soil. Details of the emission limits set will be found in section 3. 3. 6 summarized in tabular form.

3. Details of hazardous waste incineration

Whereas chapter 2 presented the general situation with regard to the thermal treatment of hazardous wastes in the participating countries, the present chapter examines in detail the technical features, economy, costs and environmental compatibility of individual incineration plants. The data reproduced are based on the replies of the specialized questionnaire. At the time of compiling this report (March 1980) completed questionnaires had been received from 30 plant operators, distributed amongst the individual countries as follows:

- France	8
- Germany	7
- Great Britain	7
- Netherlands	1
- Norway	4
- United States	3

The design and dispatch of the questionnaires were not intended to elicit representative data concerning the incineration of hazardous wastes in the member countries.[1] The extent of the documentation available is also insufficient to provide data on which a statistical quantitative analysis can be based. It does, however, fulfil the objective originally set of describing the present state of incineration, bringing out trends and indicating main areas of emphasis in future developments.

3.1 General considerations[2] [3]

Although, like the incineration of domestic refuse, incineration of hazardous waste has been used as a method of treatment for many years. The development of the technical features of plants, the layout and the design basis has been less systematic compared with the field of domestic refuse incineration. This is chiefly due to the wide variety of hazardous waste substances which, in some cases, exhibit very divergent incineration properties and necessitate the use of installations which specifically match the latter. It is therefore important to distinguish between hazardous waste incineration plants which are suitable for only one waste (specialized plants) and those which can be used for a wide range of wastes (universal hazardous waste incineration plants). Specialized hazardous waste incineration plants include, for example, installations tailored exclusively to the incineration of liquid wastes, e.g. waste oils, or solid wastes or wastes of very restricted range of composition.

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1) In 1975, Battelle-Geneva studied more than 100 industrial waste incinerators in Europe for the French Ministry of the Environment
Dartoy, J., Simon, D.: Etude des charactéristiques et des domaines d'emploi des incinérateurs de déchets industriels - Report to the French Ministry of the Environment, Battelle-Geneva, April 1976

2) Reimer, H.: Kontinuierliche und diskontinuierliche Verbrennung von Sonderabfällen in: Sonderabfallbeseitigung, edited by Thomé-Kozmiensky, Erich Schmidt Verlag, Bielefeld 1977

3) Dartoy, J.: The incineration of hazardous waste, Process Engineering Group 191-4605/JD/dm, Battelle-Geneva, December 1979

There is thus more than one solution to the problem of the incineration of hazardous wastes.

The rotary kiln has established itself as a universal incineration system. It is suitable for the simultaneous incineration of solid, liquid and semi-solid wastes of a wide range of calorific values. It is, however, not the best solution for the sole incineration of liquid or gaseous wastes. For this purpose the chamber furnace (fixed firebox/muffle furnace/cyclonic incinerator) is more suitable. Although the simple firebox is also suitable for all types of waste, its throughput capacity is considerably reduced in the case of hazardous waste with a high solid residue content (slags/ashes) since automatic slag/ash removal presents complications. It is, in principle, possible to combine discontinuously operating muffle furnaces with continuously operating rotary kilns, and this is being considered in special cases for plants at the planning stage.

Grate incinerators for solid wastes are mainly used to burn household refuse and are not often used in hazardous waste disposal unless for co-incineration. Multiple hearth incinerators are mainly used to burn sludges, tars and hydrocarbons. They may become of major interest for the combined incineration of sewage sludge and some types of hazardous wastes (e. g. pesticides). Fluidized bed incinerators are very versatile, being used for the disposal of solid, liquid and gaseous combustible wastes. The most common applications are in the petroleum and paper industries and in sewage sludge disposal.

The following table 5[1] gives the principal advantages and disadvantages of different types of incinerators.

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[1] taking the pattern of a similar table from: Dartoy, J., Simon, D.: Etude des charactéristiques et des domaines d'emploi des incinérateurs de déchets industriels, Report to the French Ministry of the Environment, Battelle-Geneva, April 1976

Table 5 Principle advantages and disadvantages of incinerators

Type of incinerator	Advantages	Disadvantages
Chamber furnace	- simple incinerators; the only problems are the choice of waste atomization device or nozzle (burner) and the aerodynamic profile of the combustion chamber - these incinerators are very often fully automated and the personnel costs are low	- these incinerators can only handle gaseous or liquid wastes with a low content of solids
Static grate	- simple incinerators - low investment costs	- automatic feeding and ash removal systems present complications - difficulties maintaining certain incineration parameters during operation; fluctuations could be remarkable
Moving grate	- good combustion due to good penetration of combustion air through the waste and mixing of secondary air with the flue gases	- risk of blockade and deterioration of grates - local superheating due to high calorific values of hazardous wastes - early melting of plastics and its leaking through the grate - more or less only suitable for solid wastes
Static hearth	- simple incinerators, investment costs can be kept low for simple hearth - easy to be adapted for pasty residues with a low melting point and little combustion residues	- most of these incinerators have manual feeding and ash removal systems - combustion efficiency often not satisfactory

Moving hearth	too little examples to draw general valuation	
Rotary kiln	- incinerator permits simultaneous incineration of solid, liquid and gaseous wastes - good mixing and combustion of waste because of the continuous rotation of the drum - because of high combustion temperatures sintering or granulating of ash/slag and minimizing of its delution	- relatively low penetration of combustion air into waste - rather low volume of combustion chamber in comparison to the outer measurements (economy of space) - necessity of an after burning chamber as an additional device - mechanical problems an packing problems - problems with kiln refractory
Fluidized bed	- high thermal capacity which enables to diminuish the dependence of the combustion parameters fluctuation from input chargings - incinerator permits simultaneous incineration of solid, liquid and gaseous wastes - good heat transfer through conduction and convection - equal temperature throughout the whole bed which lifts the wastes very fast to combustion temperature	- preshredding of waste down to a grain size similar to the one of the fluidized bed material 1) - heavy dust load of flue gases with the necessity of corresponding filter devices

3.2 Layout and design

The fundamental basic data required for the design of a hazardous waste incineration plant are the volume and composition of the substances to be

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1) This size reduction is often extremely difficult with hazardous wastes and therefore the major limitation to a more widespread application of fluidized bed reactors so far.

incinerated. It is, however, difficult to obtain reliable data. The differences which exist between the establishment of an incineration plant serving one industrial concern and a plant with a supra regional catchment area have already been indicated. It is therefore generally necessary to equip a hazardous waste incineration plant with the greatest possible flexibility regarding both throughput volume and the physical and chemical properties of the substances to be incinerated. This applies not only to total volumes, maximum values etc. but also to the proportion of the individual groups of substances to each other. The energy crisis, for example, resulted in far fewer liquid substances of high calorific value being treated as waste. A hazardous waste incineration plant so designed that it is dependent on the constant input of liquid material of high calorific value may consequently encounter difficulties or lead to disproportionately high running costs due to the use of primary energy.

Experience shows that the construction of hazardous waste incineration plants is an economical proposition only where the thermal load is approximately 25 GJ/h or more. This is approximately equivalent to throughputs of 1 t/h, 25 t/d and 8.000 t/a.

This technical limit illustrates the statement made above that hazardous waste incineration plants are practicable only for large industrial concerns with corresponding volumes of waste or for operations at a regional level.

Having regard to the transportability of the rotary kiln by road, the outer diameter is limited to approximately 3.50 to 4.00 meters. The length of the cylinder depends on the required combustion time for the material to be incinerated and is at least 8.00 meters but rarely exceeds 15 meters. With these outer dimensions approximately 15 Gcal/h, equivalent to 63 GJ/h, can be converted in the rotating cylinder, i.e. - depending on the calorific value - 2 to 6 t/h. Throughputs of more than 6 t/h pose difficulties even with correspondingly low calorific values and when thermal load requirement is met,because an unfavourable change quickly occurs in the conditions for heat and mass transfer. Recently, however, rotary kilns with a thermal load of more than 100 GJ/h have come into operation and are providing evidence for future development.

Experience from general industrial furnace construction shows that the thermal load of muffle furnaces,which in continuous operation are suitable chiefly for the destruction of liquid and low-ash semi-solid wastes , is far higher than the level which is of interest for special waste incineration. The limit is dependent less on the technology of the incineration system than on the occurence of waste.

For multiple hearth incinerators for incineration of sewage sludge inner diameters of up to 7 meters are known with up to 14 hearths. The thermal load for fluidized bed reactors for sewage sludge can be up to 70 GJ/h and more per unit.

Table 6 gives the theoretical capacity (t/h) and the maximum permissible theoretical thermal load (GJ/h) for the selected incineration plants. The figures in general confirm the statements made.

Table 6 Range of capacity and thermal load

	Rotary kiln	Firebox	Grate	Fluidized bed		ND
Number	15	11	1	1	(1)	1
theoretical capacity (t/h)	2 - 6, 2	0, 4 - 5, 0	6, 5	0, 4	(ND)	
thermal load (GJ/h)	20 - 160	1, 2 - 150	13	8	(ND)	

ND = No details available

3. 3 Technical features of plants

In this section a number of basic plant components will be described which have proved useful or necessary for hazardous waste incineration plants. As far as possible, the relevant details which have been obtained from the questionnaires will be reproduced in tabular form.

3. 3. 1 Delivery of wastes

The wastes are usually delivered by private collection and transport enterprises as well as the waste generators themselves if wastes from other sources are accepted. Public collection and transport facilities which are used for conveying domestic wastes were used in only one case for 10 % of the waste treated.

Delivery of waste is made predominantly by truck in drums (17 plants), by tanker lorry (20 plants), by pipeline (4 plants) or by rail (2 plants). Transport by ship or barge was not mentionned. It is, however, well known that transport by ship has a significant role in incineration at sea (delivery to the port where the incineration ship will pick up the wastes, via inland navigation).

The containers used for conveying the waste are predominantly for one-way only and are more rarely returnable. The capacity of these containers is determined by

- the volume of waste produced by the waste generator
- the method of transport of the containers
- the size of the container feed system at the furnace (in the case of one-way containers), but chiefly by
- the thermal and mechanical loading capacity of the furnace lining in the region of the waste input. Considerable stress is placed on the li-

ning by the sudden release of heat in conjunction with incomplete combustion of the gases (reducing atmosphere) as well as by the weight and the material of the container.

The results of the questionnaire confirmed the experience that only containers with capacities up to approximately 200 liters are used. Common container sizes are

- 22,5 l
- 35 l
- 60 l
- 100 l
- 200 l
- >200 l

One plant operator also accepted 4,5 l containers.

In France the delivery of waste via containers represents approximately 15 % of the total amount received by the treatment plants, each of which handle about 800 to 2.000 containers per month. In certain cases the demand is greater but the capacity of treatment centers to handle containers is limited because of storage security problems. The container sizes used are usually

- 225 l (normal container in France, Ø = 585 mm) and
- 217 l (= 55 U.S. gallons, Ø = 571,5mm).

Efforts are being made to standarize container sizes for 225 liters with the possibility of common storage together with the 217 liter containers. Difficulties remain in the stocking of containers of different origins.

A very small amount of wastes is delivered in France in 60 and 120 l containers. 1) If containers contain liquid wastes (about 5 %) they are

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1) The contrary applies to the Netherlands where in case of the AVR the maximum container size is up to 60 liters. The normally used size is the maximum size because of cost problems. Smaller containers are used in special cases, e. g. solvents and other highly inflammable products.

emptied, incinerated and sold after crushing. Containers with semi-solid wastes (5o to 6o %) or solid wastes (4o to 5o %) are generally incinerated after crushing or compaction.

The area of handling/charging was not covered by the questionnaire. In general, however, the following systems have proved valuable for handling the material to be incinerated after pretreatment and for charging the incinerators:

- solid materials	bunkers, grab cranes
- semi-solid wastes where not pumpable	heated coffered bunkers, special grab cranes
- semi-solid wastes where pumpable after heating	heated tanks, positive displacement pumps
- steel containers, large plastic drums, combustible one-way containers	separate container storage, if necessary with protective atmosphere; transport by special lifts or bogies
- liquid wastes	above-ground heated tanks, positive displacement pumps of various designs

Special care must be taken in this area to observe the safety regulations. In order to discover which wastes are delivered to the plants or which wastes are not accepted, question 6 on the questionnaire contained a list of the possible types of waste. This list was identical to the one which appeared in question 1 of the general questionnaire. Table 7 shows the types of waste delivered in the order of their frequency.

Table 7 Types of wastes delivered to plants

No / Type of waste		Number of mentions
12	solvent wastes and sludges	26
1	waste mineral oils	25

8	varnish and paint wastes and sludges	24
9	plastics, rubber and latex wastes	23
3	oil emulsions and oil mixtures	22
11	phenolic wastes	22
4	mineral oil sludges	20
7	glue, putty and non-congealed resin wastes	19
6	grease and wax wastes	19
10	plastics, rubber and latex sludges and emulsions	17
13	pesticide wastes	17
14	organic wastes containing halogen, sulphur or phosphorous compounds	16
5	refinery wastes containing mineral oil, incl. acid tar and spent clay	15
2	drilling and grinding emulsions	14
21	industrial effluents	13
22	industrial effluents treatment sludges	13
19	acids	9
18	pickling liquors from metal finishing	6
20	alkalis	6
15	cellulose production and processing wastes	5
23	water treatment sludges	4

-	cyanides, chromic acid	2
24	sewage treatment sludges	1
16	tannery wastes	1
17	odorous food and spice processing wastes	1
-	PCB wastes	1
-	packing materials	1

The specifications concerning types of waste not accepted can be generalized only with regard to

- explosive substances and
- highly radioactive substances.

The other replies must be seen in each case in the context of the particular plant. The following are selected replies:

- wastes having high Cl_2, S, N_2 and P contents
- PCB
- domestic refuse, sewage sludge
- wastes containing lead, mercury, cadmium, arsenic, antimony, organic sulphur and phosphorous
- substances with more than 1 % Cl_2 or other halogenes
- certain carcinogenic substances

3. 3. 2 Control of incoming wastes - analytical procedures

Careful control of wastes delivered to the plant must be seen as the initial stage of pretreatment. Since for hazardous waste incineration plants it is necessary to analyse the substances delivered to establish their most important physical and chemical properties, this will, in general, necessitate the provision of chemical and physical testing facilities (which also emerges from the replies to the questionnaires, tables 8, 9 and 10).

Table 8 Determination of waste properties

Determination of weight by

Constant weighing	17
Estimates	5
Occasional weighing	4
No determination	1

Determination of volume by

Measurement upon delivery	10
Estimates of the carrier volume	8
Estimates of container volume	6
No determination	4

Identification of waste by

Sample analysis prior to delivery	22
Constant analysis	18
Visual inspection upon delivery	16
Analysis at regular intervals	8
Analysis at cases of doubt	8
No identification	1

(multiple answers possible)

As can be seen from table 8, the determination of weight as well as the identification are applied extensively. The provision of information about the nature and amount of the waste received is essential both for technical reasons (storing, mixing, pretreatment, incineration) and financial reasons (costing and a basis for allocation of financial aids), as well as controlling the transportation and for statistical/planning aspects.

Table 9 Determination of physical properties

Property	Number of plants
calorific value	■■■■■■■■■■■■■■■■■■■■■■■23
water content	■■■■■■■■■■■■■■■■■■■19
suspended solids content	■■■■■■■■■■■■■■■■■■■19
flash point	■■■■■■■■■■■■■■■■■■18
ash content	■■■■■■■■■■■■■■■■16
specific density	■■■■■■■■■■■■12
ignition temperature	■■■■■■■7
explosion limits, range of ignition	■■■■■5
viscosity	■■■■4
boiling point curve	■■■3
vapour pressure	■■■3

With regard to the first five properties a considerable measure of agreement can be observed. Similar agreement on the determination of chemical properties can be observed in table 10, particularly concerning the halogen compounds and heavy metal contents.

Table 10 Determination of chemical properties

Property	Number of plants
pH	■■■■■■■■■■■■■■■■■■■■ 20
halogenated organics	■■■■■■■■■■■■■■■■■■ 18
lead	■■■■■■■■■■■■■■■ 15
mercury	■■■■■■■■■■■■■■ 14
cadmium	■■■■■■■■■■■■■ 13
arsenic	■■■■■■■■■■■■■ 13
chromium	■■■■■■■■■■■■■ 13
copper	■■■■■■■■■■■■■ 13
zinc	■■■■■■■■■■■■■ 13
vanadium	■■■■■■■■■■■■■ 13
nickel	■■■■■■■■■■■■ 12
iron	■■■■■■■■■■■■ 12
organic compounds (major groups)	■■■■■■■■■■ 10
organic silica compounds	■■■■■ 5
beryllium	■■■■■ 5
sulphur	■■■ 3
cyanides	■■■ 3
cobalt	■ 1
aluminum	■ 1
antimony	■ 1
sodium	■ 1
NaCl, $AlCl_3$, Al_2O_3	■ 1
potassium	■ 1

Biological properties (toxicity, biodegradability etc.) were not determined in any of the plants questionned.

Tables 9 and 10 only give indications of the extent to which physical, chemical and biological properties are determined and do not provide any information about the methods used in the analysis.

In the following lists are given the analytical methods as they were communicated for the individual parameters by the participating countries.

Physical properties:

1.) Calorific value	mainly bomb calorimeter in one case combined with ultimate analysis:
2.) Water content	- Karl Fischer - Dean and Stark reflux - Drying at 105° C, 2 h - Xylol-method - Distillation - Visual
3.) Suspended solids content	- Filtration (gravimetric) - Centrifuge - Decanting (Imhoff funnel) - Visual inspection
4.) Ash content	- Annealing at 800° C, 2 h - DIN 51 721 in oxid. atmosphere - Calorimeter residues
5.) Specific density	- Hydrometer - Differential weighing (e. g. Pyknometer) - Aerometer
6.) Vapor pressure	- References by waste generator
7.) Ignition temperature	- Open crucible - DIN 51 974
8.) Flash point	- Pensky - Mertens - Open crucible - Abel Benski DIN 51 755
9.) Explosion limits, range of ignition	- DIN 51 794 in air/oxygen - Hülsenversuch, Fallkammer
10.) Boiling point curve	- Distillation
11.) Others: tank input	A) Polymerisation test B) Mix test

Chemical composition:

1.) pH	- potentiometer (pH electrode) - Titration - litmus paper
2.) Organic compounds	- IR - TOC - GC
3.) Halogenated organics	- ultimate analysis - GC - according to Schöninger - Wurzschmitt fusion process and potentiometric titration - ignition and gas analysis - back titration of acid gases from bomb calorimeter
4.) Organic silica compounds	- ultimate analysis - Photometer - AAS - estimated from ash
5.) Mercury, cadmium, lead, arsenic, copper, zinc, beryllium, chromium, nickel, vanadium, iron	- atomic adsorption spectroscopy[1]
Exceptions:	
- arsenic - vanadium	- Photometer
- zinc	- colorimeter analysis

3.3.3 Pretreatment

Far greater significance attaches to the pretreatment of special wastes for incineration than is the case, for example, with the incineration of domestic refuse. Whilst in the latter case pretreatment is limited to milling or pulverizing the bulky refuse and, if necessary, mixing in the refuse bunker, in the case of special waste incineration plants extensive pretreatment of the waste is required.

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[1] Two other analytical methods for heavy metals are applied as far as household waste is concerned:
- X-ray fluorescence spectroscopy
- emission spectroscopy

Table 11 Pretreatment of wastes

Type of pretreatment	Number of plants
filtration	12
homogenisation	12
decanting	10
emulsion separation	7
liquification by heating	7
milling, pulverization	7
neutralization	6
detoxification	4
dewatering	3
distillation, fractionation	3
screening	1

The plant operators questioned reported that pretreatment generally took place in the incineration plant itself. Only when further supraregionally operated incineration plants are constructed, to which transfer and collection stations are linked, it is to be expected that a part of the pretreatment function will be shifted to the transfer and collection stations, predominantly in order to reduce the volume of waste to be transported and to increase safety during transportation.

3.3.4 Incineration

The incineration of hazardous wastes is a process which has gained increasingly in significance in the last 20 years. Table 12 shows the year in which the individual plants were commissioned.

Table 12 Commissioning of plants

Year	64	67	68	69	70	71	72	73	74	75	76	77	78 / 79
Number	1	1	0	1	0	2	2	3	5	3	2	4	3

1)

Six plant operators plan extensions to their plants.

A trend towards the construction of incineration plants can be deduced from table 12. The correlation between the number of plants which were commissioned in 1973 - 75 (11) and the so-called energy crisis, however, should be regarded as coincidental since there is a time-lag of approximately 5 years between the planning and the commissioning of a plant. Since our questionnaires contained no details of new plants planned it is not possible to make reliable deductions regarding the future development of incineration. This will be determined essentially by the following factors:

- developments in the volume of waste generated - having regard to waste reduction and waste avoidance
- development of alternative treatment technologies
- conditions placed on incineration on environmental protection grounds, and thus
- development of costs,
- better supervision of waste generators and waste streams through the control of statutory bodies,
- potential citizen opposition to alternatives such as land disposal (this seems to be an interesting argument because often the opposite is the case).

The question of the year of commissioning should be looked at against the background of the "state-of-the-art" for the establishment of any correlations (see also section 3. 3. 5 to 3. 3. 9).

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1) three plants without specification

The replies to the questions on "reactor system" and "thermal load" are given in table 6. The throughputs of the plants questioned fluctuated between 10.000 and 100.000 t/a with concentrations around 10.000 and 50.000 t/a. For details see table 20.

The reaction chambers of the plants were in 20 cases given as open reactors and in 6 cases as closed reactors. In 21 cases the throughput of waste was given as continuous and in 6 cases as discontinuous (2 plants did not specify). 21 plants have afterburner chambers and 6 plants do not.
In conjunction with rotary kiln reactors it is not generally possible to dispense with an afterburner chamber in order to ensure complete combustion of the volatile constituents.

The reactors were in all cases heated directly by combustion of the wastes with excess-air coefficients of $\lambda = 1.1$ to $\lambda = 3$.[1] The pronounced scatter of the values obtained can be explained by the dependence of the volume of air on the composition of the incinerated wastes, the fuel system and the slag softening point (the softening point of the inert constituents of the waste). Nearly stoichiometric combustion is at all events possible in the afterburner chamber although the 2 replies do not support this statement ($\lambda = 1.5 - 2.4$).

Of the 21 plants which have afterburner chambers, 10 burn liquid wastes in the afterburner. In this connection the use of additional fuels is of interest. They are used when required:

- in the reactor in 15 plants
- in the afterburner in 10 plants.

From indications given it can be deduced that this is predominantly the case when starting up the plant or in order to maintain a certain minimum temperature.

The question concerning the reactor material was probably phrased too generally to obtain specific answers. The information provided consisted of such general indications as "brickwork" or "steel casing with refractory brickwork". It is, however, known that the lining of rotary kilns may vary over the length of the cylinder, e. g. fireclay (52 % Al_2O_3) at the front and chrome magnesia at the rear. Whether individual operators put additives (e. g. clay or bleaching earth) with the waste in order to protect the lining with the film of slag was also not clear from the answers. For details of operating problems with linings see section 4. 4.

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[1] an excess-air coefficient of $\lambda = 1{,}1$ means 10 percent of excess air,
of $\lambda = 3$ means 200 percent of excess air,
of $\lambda = 1$ means stoechiometric incineration

The process temperature in the reactor was reported to be between 900° K and 1. 600° K with a median value of around 1. 300° K. Temperature in the afterburner chamber was reported to be between 1. 000° K and 1. 600° K with a median value of around 1. 400° K.

Residence times in the reactor were
- between 20 and 120 minutes for solids
- between 2 and 15 seconds for liquids/gases

and in the afterburner chamber 2 to 5 seconds.

As previously mentioned, one of the main criteria for using incineration for hazardous waste disposal is the destruction ratio of a given material besides volume reduction and energy use. This depends largely on the parameters incineration temperature and residence time. Experience shows that most organic hazardous wastes can be virtually completely destroyed at about 1.300° K with a residence time of at least two seconds. This corresponds favourably with the results drawn from the various answers to the questionnaires.

3. 3. 5 Flue gas cooling

The dusts are removed from the flue gas by filters (cyclones, electrostatic filters) and the noxious gases (and also the dusts) are removed by wet scrubbing. Whilst for the purposes of electrostatic cleaning, cooling of the flue gas down to approximately 620° K is absolutely essential, the value of such cooling for wet scrubbing is purely economic (saving of cooling water).

In discontinuously operating incineration plants the flue gas can be economically cooled by
- injection of water
- addition of cooling air.

The consequent increase in the volume of the flue gas to be cleaned is accepted since indirect air cooling by surface heat exchange has caused problems through fouling up on the flue gas side and short running times.

In continuously operating incineration plants it is feasible to combine flue gas cooling with partial utilization of the sensible heat of the flue gas. This is done chiefly by means of heat recovery boilers which generate steam or hot water. Owing to the corrosive nature of flue gas and the higher flue gas temperatures, in some cases, by comparison with domestic refuse incineration plants, specialized designs have been developed for heat recovery boilers linked to special waste incineration plants.

A special type of boiler, the so-called "fin wall boiler" (literal translation of the word "Flossenwandkessel") has been developed mainly from BASF together with well-established boiler-manufacturers.[1)]

Other boiler designs may also be considered, taking into account the limitation of flue gas temperature (1.000° K) before it enters the first flue of the boiler.

Amongst the participating countries it was felt that more information on the boilers was required as this technique of waste heat utilization is not

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1) More details can be found in the report "Corrosion in refuse incineration plants" from Fäßler, Leib and Spähn, Mitteilungen der VGB, Heft 2, 1968, S. 126 - 139

practiced to a large extent at the existing facilities.

3.3.6 Flue gas cleaning

The type and quantity of the pollutants contained in the flue gas depend primarily on the composition of the wastes, the type of incineration system, the controlling of the flue gas in the furnace and the incineration temperature. Separate gas cleaning processes are normally required.

Both dust removal and scrubbing plants are possible methods of flue gas cleaning. The noxious gas content in hazardous waste incineration plants is in general so high that dust removal alone is insufficient. Table 13, below, gives an outline of maximum pollutant concentrations as established in numerous emission measurements at large municipal and industrial incineration plants in the Federal Republic of Germany.

Table 13 Concentrations of harmful constituents in the flue gases

Solids	Dust	2000 - 15000	(mg/m^3)
Noxious gases	Cl^-	< 1500	(")
	F^-	< 20	(")
	CO	< 5000	(")
	SO_2	< 1000	(")
	NO	< 500	(")
	NO_2	< 50	(")

The figures for SO_2, Cl^- and F^- apply only where the substances being incinerated do not have extremely high sulphur, chlorine or fluorine contents.

All plant operators questioned, with a few exceptions, provide flue gas cleaning equipment. Table 14 gives the type of flue gas cleaning operated.

Table 14 Type of flue gas cleaning

- purely dust removal	7	electrostatic precipitator	4
		bag filter	2
		cyclones	1
- removal of dust and noxious gases	14	scrubbing system	10
		electric filter and scrubbing system	3
		cyclon and scrubbing system	1
- no removal	3		
- no answers	4		

The removal of dust is possible with cyclones, bag filters, electrostatic cleaning systems and wet scrubbers. Cyclones do not achieve a sufficient removal efficiency, particularly with fine particles. Bag filters demand extensive cooling of the flue gases and are very expensive. Although wet scrubbers afford the possibility of simultaneously eliminating the noxious gases, disadvantages are that these units require large throughputs of water and considerable reductions in pressure occur. Moreover, the particulate matter must then be separated from the scrubber effluent in a further stage in the process and the resulting sludges de-watered. An additional problem is caused by the heavy metals found in elevated concentrations in particulate form which would go into solution with wet scrubbing. Electrostatic filters are in common use on account of the high removal efficiency required.[1] Efficiencies from 98 to over 99 % are being achieved. In newly erected plants in which the elimination of toxic gases becomes necessary, the separation and dry removal of dust (e. g. by means of electrostatic filters) and wet removal of noxious gases will become more common.

Various types of scrubber have proved reliable for the absorption of the noxious gases HCL and HF from the flue gases. All of these make use of the solubility in water of the gases to be removed but, in addition, the removal of SO_2 is necessary which requires the use of alkaline absorption agents on account of its lower solubility in water.

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[1] Note that silica content of the flue gas can affect the efficiency of electrostatic precipitators.

Table 15 gives the removal efficiencies of wet scrubbing systems in two different hazardous waste incinerators in the Federal Republic of Germany.

Table 15 Wet scrubbing removal efficiency

Plant	noxious gases	crude gas (mg/m^3)	clean gas (mg/m^3)	efficiency
A	HCl	7.450	30	> 99
	SO_2	6.255	600	> 90
	dust	8.000	30	> 99
B	HCl	2.400		≥ 97
	SO_2	4000-10000		ca. 80

Dry removal processes which are based on the absorption of the toxic gases by means of suitable absorption agents (e.g. lime CaO or NaOH) with subsequent dust removal have not yet achieved the necessary removal efficiency at acceptable costs. Since the introduction of these processes would confer substantial advantages, a considerable amount of research and development work is being carried out in this field. These processes are already now designed or applied to some power plants in Denmark, to some ceramic industries in Italy (for HF) and to some municipal waste incinerators in Italy and the Federal Republik of Germany.

The harmful constituents contained in the flue gases of the individual plants quoted in the replies to the questionnaire are shown in table 16 as far as they were measured. They are compared with the maximum limits prescribed by the authorities. It may be of interest to note that in one case emission limits for the plant operation were specified for certain heavy metals (plant 3.1) and in another case limits for hydrogen cyanide (5,5 mg/m^3) and hydrogen sulphide (7,1 mg/m^3) (plant 5.5).

Some figures in table 16 require further checking since it has been assumed that units have been confused here. It has also been noted that for somes plants emission limits for Cl^- are quoted but no corresponding harmful constituent contents in the pure gas are given. This can perhaps be explained by the lack of continuous measuring processes for Cl^-. For all other harmful constituents continuous measurement is likely to become established in the long term.

Comparison of emission limits with the year of commissioning shows almost without exception a progressive tightening of standards followed by a corresponding reduction in the amounts of harmful constituents emitted. Since the report is more concerned with specific amounts of harmful constituents, it is not possible to indicate trends with regard to overall emissions.

In the past analysis was mainly carried out for the more significant flue gas components such as mentioned in table 16. However, some other components have recently become the basis for concern from the incineration of hazardous wastes1) and in this context it may be difficult to remove volatile metals, such as lead, cadmium, zinc, mercury, arsenic and antimony from the effluent gases. As the gas cools, metal or metal oxide fumes may form, charaterized by their very small particle size which is typically less than 0,1 micron. An available efficient gas cleaning system for such fumes is the bag filter which has many disadvantages for use on an incinerator2). Materials containing substantial concentrations of these metals are thus best not incinerated until better gas cleaning divices are developed.

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1) Wilson, David C.: Recent developments in the management of hazardous wastes, Atomic Energy Authority, Harwell, Oxfordshire, Great Britain, September 1978

2) It is of interest, that bag filters have been used very successfully to capture arsenic compounds from glas-making furnaces.

An additional environmental burden which can result from the incineration of hazardous wastes should be mentioned in this context.1) - 6)

There are several groups of thermally stable chlorinated organic compounds including the polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and hexachlorobenzene, which may originate from many combustion processes. In general they are not normally present in the fuel or waste, but are formed during the combustion process from aromatic and possibly aliphatic chlorinated organic compounds. Because of the very low concentrations in which they occur (< 0,1 ppm) the identification of these pollutants is very difficult. However, investigations carried out in the Netherlands, Switzerland and the US have confirmed the existence of some of the above-mentioned compounds in the flue gases from incinerators.

In all 75 and 135 positional isomers exist for the PCDDs and the PCDFs, respectively. The toxicity of only a small number of these compounds has been investigated. The most well known, a particular tetrachlorodibenzodioxin (2,3,7,8-TCDD, the "Seveso" poison), is an extremely poisonous substance; it also has teratogenic, mutagenic and carcinogenic properties. The toxicity of the other isomers is

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1) Langer, H.G.; Brady, T.P.; Briggs, P.R.: Formation of Dibenzodioxins and other Condensation Products from Chlorinated Phenols and Derivatives in Environmental Health Perspectives, September 1973, page 3-7

2) Kearney, P.C.; Woolson, E.A.; Isensee, A.R.; Helling, C.S.: Tetrachlorodibenzodioxin in the Environment: Sources, Fate, and Decontamination in Environmental Health Perspectives, September 1973, page 273-177

3) Ahling, B. and Johansson, L.: Combustion Experiments using Pentachlorophenol on a Pilot Scale and Full-Scale in Chemosphere Nr. 7 1977 page 425-436

4) Ahling, B.; Lindskog, A.; Jansson, B.; Sundström, G.: Formation of Polychlorinated Dibenzo-p-dioxins and Dibenzo-furans during combustion of a 2,4,5-T Formulation in Chemosphere No. 8 1977, page 461-468

5) Olie, K.; Vermeulen, P.L.; Hutzinger, O.: Chlorodibenzo-p-dioxins and Chlorodibenzofurans are trace components ... in Chemosphere No. 8 1977, page 456-459

6) Buser, H.R.; Bosshardt, H.-P.; Rappe, Ch.: Identification of Polychlorinated Dibenzo-p-Dioxin isomers found in fly ash in Chemosphere No. 2 1978, page 165-172

less than one-tenth of that of 2,3,7,8-TCDD. Investigations in the Netherlands at 9 household waste incinerators showed up to 400 ppb TCDD (all isomers) present in the fly ash. The proportion of the "Seveso" poison was relatively small (about 3 % of the total amount of TCDD compounds present) but the other compounds (mainly hexachlorodibenzodioxins) are also potentially dangerous.

Only a small proportion of the chlorinated organic pollutants emitted from wast incinerators are of such high toxicity. However, the test results available are insufficient whether the nature and quantity of chlorinated organic compounds in incinerator emissions represent a health hazard. Detailed investigations and extensive monitoring are necessary to obtain reliable, representative results on which the danger of these emissions can be assessed objectively, and any programme aimed at reducing the concentrations present can be based.

Table 16 Volumes of harmful constituents (mg/m^3) and emission limits (mg/m^3)

No. of plant	year of commissioning	Cl^-		F^-		SO_2		NO_x		CO		Dust	
		volume	limit	volume	limit	volume	limit	volume	limit	volume	limit	volume	limit
1. 1	1981	< 50	< 100	< 2, 5	<2, 5	< 200	< 200	< 400	<400	< 100	< 100	< 75	<75
1. 3	1967	<250	< 1000	< 10	< 15	< 350	<2500	400-800	<1000	< 30	<100	80-120	<150
1. 4	1976	< 50	< 100	< 3	<10	< 300	<1250	< 400	<1000	< 100	< 100	< 20	<100
1. 5	1960-78 3)	< 90	<100	0	-	<300	-	<200	-	80	<100	<100	<100
1. 6	1977 3)	<100	<100	< 5	< 5	<2100 1)	<2100 1)	-	-	-	<100	<100	-
2. 1	1971	-	-	-	-	-	-	-	-	-	-	< 230	<230
2. 2	1972	-	-	-	-	-	-	low	-	mini-mized	-	-	-
2. 3	1969												
3. 1	1973	500	500	4	2	traces	1300	-	-	-	-	80	50
4. 1	1975		-		-		-		-		-		100
4. 2	1964	400	-	5	-	200	-	300	-	-	-	-	50000 2)
4. 3	1978	-	-	-	-	very little	-	0, 01 %	-	0, 01 %	-	-	15o
4. 4	1978/79		4)		-		-		-		-		2, 4 kg/h
5. 1	1974	-	230	-	-	-	-	-	-	-	-	370	460
5. 2	1974	-	230	-	-	-	-	-	-	-	-	130	460
5. 3	1977	-	230	-	-	-	-	-	-	-	-	70	115
5. 4 2)	1975												
5. 5	1974	13	460	-	96	152	9200	39	-	220	5800	-	-
5. 6	1971	<100	468	nil	-	< 400	468	not known	-	nil	-	not known	-
5. 7	1973	<100	468	nil	-	<200	468	not known	-	nil	-	not known	-
6. 1	1977	-	-	-	-	-	-	-		<0, 1 %		70	150-750
6. 2	1975	30 ppm	100	-	0	200 ppm	400	10 ppm		<0, 1 %		<100	100
6. 3	1972												
6. 4	1973	0		0		4000		7		<1 %		100	150
6. 5	1974												
6. 6	1977	40	150	-	5	60	500	50	500	10	150	120	150
6. 7	1976		225		5		500		500		500		225
6. 8	1974		-		-		-		-		>o, 1 %		500-1000

3.3.7 Effluent treatment

If it is not discharged untreated into the receiving stream, the effluent produced by the wet scrubbing of the flue gas is neutralized and solids are separated out. The volume of water arising from gas scrubbing is between 25.00 and 31.00 l/t of waste and in one particular case 155.000 l/t.

Remarks to table 16 on page 55:

1) together with a combined oil fired steam boiler
2) volume of harmful constituents under investigation
3) additional limits for $C_{org} < 50$ mg/m^3
4) 0,5 kg/h as HCl

" - " as stated in the questionnaires; no indication means no answer

Three plant operators specified the composition of their scrubbing effluent as follows:

Table 17 Composition of gas scrubbing effluent

	Plant I	Plant II	Plant III	
			1. Step (HCl)	2. Step (SO_2)
Evaporation residue		11 g/l	1 g/l	0,4 g/l
pH	7	1 - 2	0,1	7,5 - 8
Sulphate	0,2 g/l	3 g/l	80 mg/l	200 mg/l
Chloride	0 - 3 g/l	3,5 g/l	0,5 g/l	80 mg/l
Ca	0 -50 mg/l	$<$ 5 mg/l	-	-
Mg	0 -50 mg/l	$<$ 5 mg/l	-	-
Pb	-	$<$ 0,04 mg/l	-	-
BSB$_5$ 1)	-	-	18 mg O_2/l	18 mg O_2/l
CSB 1)	-	-	80 mg O_2/l	30 mg O_2/l

Owing to the increasing burden of salts and heavy metals in rivers it is to be expected that in future desalination of scrubbing water and precipitation of heavy metals will be increasingly required as well as a neutralization and separation of solids.

In order to completely avoid the problem of effluent, dry sorption processes are currently under development. With comparable operating costs (especially consumption of chemicals), however, such processes do not as yet achieve the concentration limits required in the Federal Republic of Germany.

The sludges arising from gas scrubbing or effluent treatment are, in some plants, dewatered (vacuum filter) or mixed with other chemical wastes in order to obtain a product which can be landfilled, usually on specially

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1) corresponding to the initial loading of the recycled scrubbing water

equipped landfills, and are not recycled.

A completely satisfactory solution for the final treatment of the dilute sludges from the scrubber effluent has not yet been found. If added to the slags together with the ash from the electrostatic filters, there exists the danger of leaching out of these components. Discharge to sewer is not usually acceptable.

In some specially constructed waste incineration plants HCl, HF and, to some extent, SO_2 are removed in an initial scrubbing stage. A second scrubbing stage is provided for the absorption of SO_2 and the separation of fine dusts (metal oxides) and aerosols (condensing salts). The effluent produced in the two scrubbers is injected into a dry reactor located between the heat recovery boiler/electrostatic filter, on the one side, and the gas scrubber on the other. In this dry reactor the water evaporates due to the sensible heat of the flue gas. Coarse solids are removed in a dry state in the reactor itself, and final solids in two cyclones connected upstream of the reactor. Residual dusts are separated out in the subsequent scrubbers and fed back into the dry reactor with the effluent. It is hoped that this circulation will lead to an agglomeration of the solid harmful constituents into larger particles.

3. 3. 8 Treatment of solid residues

The solid residues which occur in incineration plants for hazardous wastes are

- slag from the reactor and, where present, the afterburner
- dusts from cyclones, electrostatic filters and other filters
- possible scrap.

The specific amount of slag corresponds to the composition of the input and was reported to range from 5 to 500 kg/t of waste. The slag is finally disposed of in landfills, either domestic/ commercial waste landfills or chemical landfills.

For fly ash the specific amount ranges from 9 to 100 kg/t of waste. It is landfilled with or without follow-up treatment. Reported variations in the composition of fly ash are reproduced in table 18.

Table 18 Average composition of fly ash (%)

No. of plant	C	S	Cl	H_2O	Al_2O_3	SiO_2	Fe_2O_3	Heavy Metals
1. 3	< 0, 03	~1	~0, 1	-	~ 20	~ 24	~ 21	< 1
1. 4	< 0, 03	~4	~2	-	5 - 15	70 - 80	-	< 1
1. 5	0 - 2	0-9	0-8	-	0 - 5	0 - 20	-	0 - 3
1. 6	2	15	8	-	3	15	40	-
4. 1					5	20	55	-
5. 4								~1
6. 4	0	8	0	0	4	15	- 1)	< 2

References to the situation in individual countries were given as follows:

Canada

At present, residues from the incinerators are landfilled but there is no information available on their long term behaviour.

Norway

At present, the residues are co-disposed with municipal waste.

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1) CaO = 30 %

Netherlands

No figures are available for composition in the case of co-incineration because this depends very much on the composition and ratio of the incinerated chemical wastes.

Nevertheless, in the case of co-incineration depending on the composition of the waste an increase in heavy metal concentration in both slag and fly ash can be observed.

Although some figures are available for a rotary kiln incinerator, it should be stressed that the samples were taken at random and cannot be considered to be representative.

Table 19 Composition of slag an fly ash

	slag ppm	fly ash ppm
Ti	36.200	22.700
V	13,5	93,3
Cr	3.680	2.570
Mn	2.180	1.980
Fe	43.800	56.600
Co	91,6	1.301
Ni	633	376
Cu	3.350	3.140
Zn	1.280	26.500
As	41	464
Se	<10	51,4
Mo	639	1.540
Ag	13	82,2
Cd	<30	1.120
Sb	422	5.180
Ba	5.090	3.440
Au	3,8	1,0

No information is available on organics in slag and fly ash.

Germany

In Germany only detailed information is available from the leaching behaviour of residues from household waste incinerators. Investigations have shown that fly-ash-free slags are only slightly leachable and, therefore, can be landfilled with relatively little harm. The case is different in the landfilling of fly ash from which harmful substances can be extensively leached: 28 times more material was extracted than from pure bottom slag. In addition fly ash contains more than 10 % soluble components whereas slag contains only 0, 4 %. The most significant components of leachates can be sodium, calcium, sulphate and chloride as well as volatile heavy metals such as zinc, lead and cadmium. It has been concluded that fly ash should no longer be disposed of together with slags and that high water solubility of some compounds must be reduced through suitable treatment such as compaction. While this is not done so far with the residues of household waste incinerators, separate landfilling of fly ash and bottom slag is applied in the case of nearly all hazardous waste incinerators. The fly ash then is either stored in special containers which go to a chemical landfill, if no treatment takes place, or it is disposed of after neutralization and fixation with lime in a chemical landfill.

France

Incineration residues (slag and fly ash as well as slurries from flue gas scrubbing) are disposed of in controlled landfills. Certain treatment centers use the slag as barrier (filling material?) or discharge the gas washing effluents into the receiving stream after appropriate chemical treatment. Analyses, currently being undertaken, for incineration residues, and specially for the volatile effluent stream, lead to the conclusion that it is convenient to treat them as hazardous wastes in specially designed and licensed treatment plants.

In General

It should be kept in mind that bottom slag from household waste incinerators, mainly grate systems, differs considerably from bottom slag from hazardous waste incinerators, mainly rotary kiln reactors. Because of the generally higher process temperature (~1.000°C versus ~800°C) and the more homogeneous nature of the input the residues appear to be more slaggy or sintered. Elution of pollutants is therefore more likely to be limited.

Fly ash from hazardous waste incinerators usually has the following properties:

- a high concentration of volatile toxic heavy metals
- a high content of watersoluble compounds such as sulfates and chlorides
- a low pH (acid) of the suspension.

The last two items promote the solubilization of the heavy metals which, as oxides, are practically insoluble in water. Therefore, if bottom slag and fly ash are disposed of separately, fly ash should be neutralized via addition of basic compounds.

3.3.9 Usable Products

The usable products of a hazardous waste incineration plant may be
- energy (as steam) and
- scrap.

With one exception (400 t/a), no information was available as to whether the scrap contained in the slag (e.g. from the containers) is separated out and supplied to smelting works for reuse.

Although it initially appears feasible to combine the cooling of the flue gas, which is indispensable for flue gas cleaning, with partial utilization of the sensible heat of the flue gas, this is the case in only nine out of twenty eight plants from which questionnaires have so far been received. The temperature of the steam generated ranges from 520 to 760°K, the pressure from 18 to 40 bars. It is mainly used for

- on-site generation of electricity
- transfer to heating plant
- industrial utilization
- preheating of wastes.

The output, which depends mainly on the product of the amount of waste and its calorific value, ranges from only 1,5 t H_2O/h up to 100 t H_2O/h.

It may be suggested that in many cases heat recovery has not been successful because of deposits on tubes, erosion, corrosion from sulphur oxides, sulphuric or hydrochloric acids due to the high dew points or the intermittent nature of the process.

However, the fact that only in a few cases the inherent energy in the waste is utilized is difficult to appreciate at a time of rising energy prices. It is reasonable to assume, however, that, particularly in the field of those hazardous wastes having high calorific values, there will be a change of emphasis since, for example in the Federal Republic of Germany, all except three smaller plants out of 41 incineration plants for domestic refuse which is of relatively low calorific value have heat utilization facilities.1) This is not to fail to recognize that, as has already been mentioned above, specially designed heat recovery boilers are required for linkage to special waste incineration plants owing to the, in some cases, corrosive flue gases and the high flue gas temperatures. In addition there may arise problems due to the penal cost for standby power from public supply and low credit for power exportation to public supply.

Indications from the French contribution are that the calorific value of industrial wastes often appears to be overestimated. In reality, the waste

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1) The situation in France is similar where two thirds of all household incinerators are equipped with heat recovery devices.

generators use more and more of the "better" waste in their own facilities as a fuel substitute and only rely on hazardous waste incinerators (supra regional type) if the calorific value of waste is very low or if the wastes are very difficult to handle because of their toxicity. The average calorific value of the delivered hazardous wastes would appear to be at present approximately 20 GJ/t.

3.4 Plant operation

Table 20 compares the essential economic data and personnel requirement with the throughput (t/a) and the heat input (GJ/h).

3.4.1 Number of employees

As far as these figures can be regarded as representative, there appears to be only a limited correlation between plant size and personnel requirement. In plants which are operated around the clock, i. e. seven days a week (this being the case in the majority of plants), five shifts or four shifts and split shifts should be assumed, if there is not to be a high level of overtime working.

3.4.2 Costs - profitability

Originally it was planned to provide data for capital costs as well as operating costs per year. But it turned out that very often the required figures were not entered in the questionnaires, so that any overview would have been incomplete and could have given rise to misinterpretation. In addition exchange rates, depreciation rates, inflation rates etc. could not always be taken into consideration. Therefore, figure 1 on page 64 has been restricted to the provision of a range of figures for the ratio of throughput to investment

Table 20 Economic and technical data of individual plants

No. of plant	Through-put (t/a)	Thermal load (GJ/h)	Personnel	Operating hours per year	Disposal costs/t
1. 1	50. 000	62, 7	50	8. 000	
1. 3	55. 000	160, 0	39	7 - 8. 000	180 DM
1. 4	15. 000	80, 0	30 - 35	7 - 8. 000	400 DM
1. 5	100. 000	350, 0	97	8. 700	140 DM
1. 6	45. 000	197, 2	33	7. 500	-
2. 1	11. 500	90, 45	11 1)	6. 500	138 $
2. 2	1. 360	20, 0	2, 5	6. 000	-
2. 3	40. 000	117, 6	55	7. 000	-
3. 1	28. 000	84, 0	~ 50	7. 000	425 hf
4. 1	3. 300	8	-	-	-
4. 2	100. 000	13	-	8. 000	150 NKr.
4. 3	500	1, 2	-	- 2)	-
4. 4	6. 000	-	-	-	-
5. 1	15. 700	60	57	6. 000	-
5. 2	15. 450	60	48	6. 000 3)	-
5. 3	13. 000	40	46	6. 000	-
5. 4	12. 000	42	26	4. 800 4)	-
5. 5	18. 000	-	16	5. 000	17 £
5. 6	18. 000	~130	10	4. 000 5)	-
5. 7	18. 000	~150	12	6. 800	-
6. 1	10. 000		20	5. 700	-
6. 2	15. 000	20	18	7. 500	
6. 3	60. 000	-	10	8. 500	-
6. 4	30-40. 000		40	7. 000	295 FF
6. 5	40. 000	-	-	7. 200	-
6. 6	13. 000	48	25	7. 500	460 FF
6. 7	15. 000	36, 8	23	8. 200	330 FF
6. 8	7. 400 6)	7, 2	5	-	-

1) only operating personnel; maintenance personnel and laboratory personnel varies

2) 5 h/day

3) 5, 5 working days per week

4) 6 working days per week

5) 5 to 6 working days per week

6) 2. 400 t/a discontinuously, 5. 000 t/a continuously treated

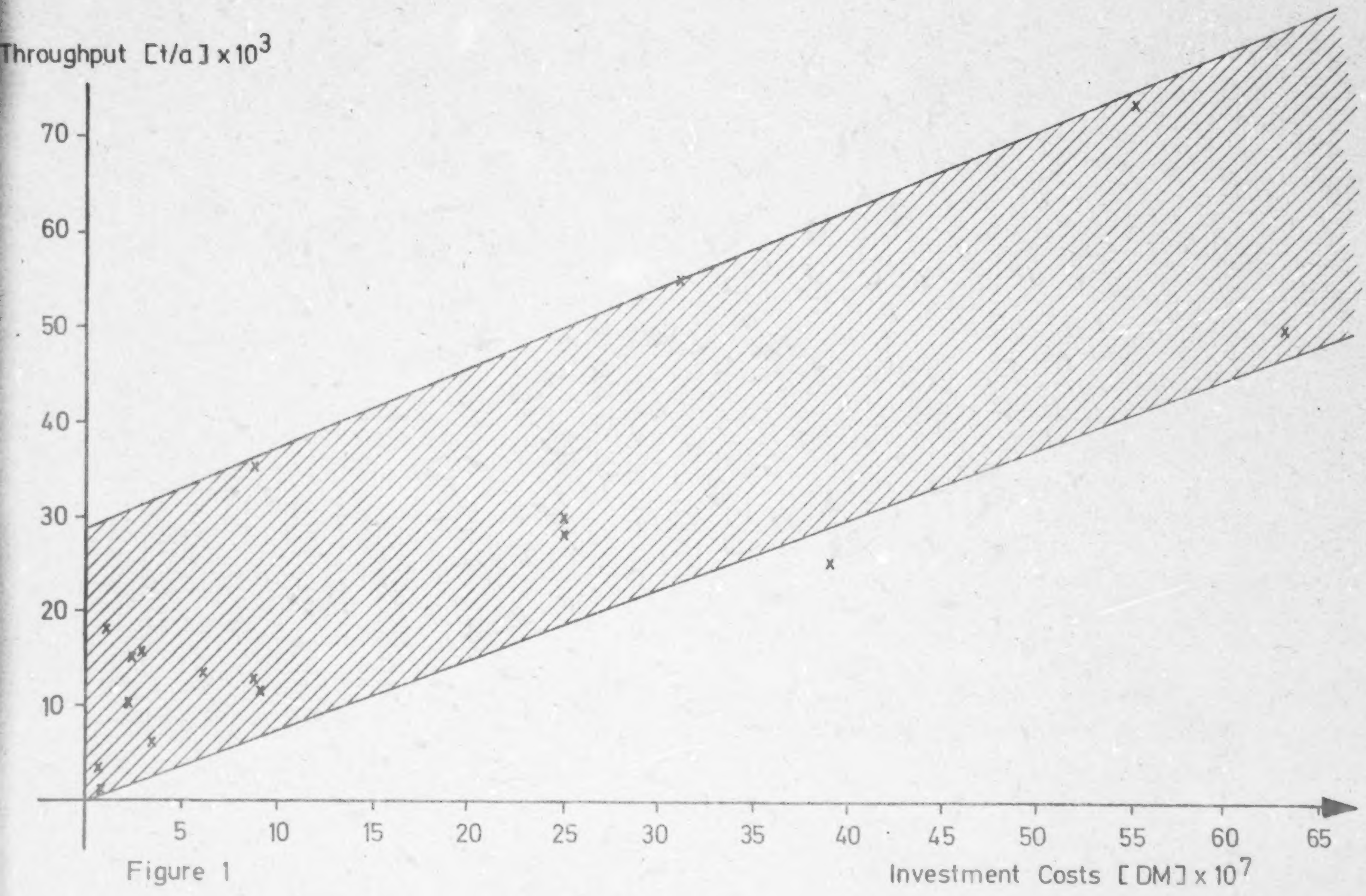
Throughput [t/a] x 10^3
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
55
60
65
Investment Costs [DM] x 10^7

Figure 1

costs. (An attempt was made to convert the annual figures but this is only likely to give an approximation).

The following figures are quoted for the capital cost of a complete special waste incineration plant (rotary kiln) for the Federal Republic of Germany (price basis 1977).[1]

Plants up to 42 GJ/h	0. 14 to 0. 19 million DM/GJ/h
Plants up to 84 GJ/h	0. 12 to 0. 167 million DM/GJ/h
Plants up to 126 GJ/h	0. 095 to 0. 12 million DM/GJ/h

These figures for specific capital outlay do not include the cost of the site or site development. But they do include, apart from the buildings, the complete fuel preparation, slag removal, flue gas cooling and flue gas cleaning systems. The Gesellschaft für Sondermüllbeseitigung in Bayern (GSB) plant in Ingolstadt - Ebenhausen

can be seen as a typical example of such a plant. Tenders were invited and the contract awarded in 1973 and the plant was commissioned in 1976. In this case the investment was 24. 0 million DM for 153. 3 GJ/h heat input with certain prepayments for final finishing work.

If these prepayments are taken into account, then there is a specific capital outlay of

~160. 000 DM/GJ/h.

For a special plant in Münster for the incineration of chemical warfare wastes with a maximum thermal capacity of 4.2 GJ/h, the capital cost for the actual incineration plant without ancillary structures was 480. 000 DM/GJ/h.

The running costs of special waste incineration plants are significantly higher than those of domestic waste incineration plants. This is related both to the higher specific capital cost and, above all, to the fact that the numerous ancillary installations for fuel preparation and pretreatment, flue gas cleaning etc. necessitate a considerably greater outlay on structural work than in the case of domestic waste incineration plants. If one takes into account the customary rates for depreciation and interest on the capital invested, repairs, servicing, maintenance expenditure, personnel, energy costs, slag transportation and disposal and water and chemical inputs, then the following approximate figures (price basis 1977) for rotary kiln plants in the Federal Republic of Germany are obtained:

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[1] Reimer, H. : Kontinuierliche und diskontinuierliche Verbrennung von Sonderabfällen, a. a. O., pp. 110 - 112

For plants up to 42 GJ/h	250 to 300 DM/t of waste
For plants up to 84 GJ/h	180 to 220 DM/t of waste
For plants over 126 GJ/h	140 to 180 DM/t of waste

In isolated cases the costs are even higher and may in extreme cases reach 400 DM/t of waste (see table 20, page 63).[1]

For examples of individual disposal prices see annex III.

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[1] After completion of this report, the pilot country became aware of a study carried out by the Association of the German Chemical Industry which will be published shortly. This report largely deals with costs of incineration of special wastes, which are summarized in table 21 without further explanation.

Table 21 Cost comparison

Plant		A	B	C	D	E	F
Thermal Load	GJ/h	100	80	115	3,5	25	10
t/a at 8.000 h		29.500	29.000	48.000	2.000	11.000	4.000
appr. calorific value of waste	GJ/t	27,1	22,4	19,2	14,1	18,2	20,2
Year of Investment		1978	1976	1977	1978	1976	1975
Total Investment	Mio DM	19,80	27,8 2)	25,0	1,60	6,023	1,50
Investment	DM/t	671	959	521	800	548	375
	DM/GJ	24,77	42,81	27,14	56,74	30,11	18,56
Electric Filter or Cyclon	Mio DM	-	0,405	1,2	0,095	-	-
Scrubber	"	2,70	0,993	1,6	0,175	0,580	0,370
Suction Blower	"	0,30	0,105	0,4	0,155	0,320	0,070
Reheating Flue Gases	"	0,25	0,598	0,5	-	-	-
Waste Water Treatment	"	0,15	0,473	n.a.	0,175	n.a.	0,010
Investment for Flue Gas Cleaning	"	3,40	2,574	3,7	0,600	0,900	0,450
	DM/t	115,25	88,76	77,08	300	81,82	112,50
related to total Investment	%	17,17	9,26	14,80	37,5	14,94	30,0
Operating Costs	Mio DM/a	3,20	9,07	8,57	0,900	3,535	0,700
Operating Costs 1)	DM/t	108,47	312,76	178,54	450	321,24	175
	DM/GJ	4,00	13,96	9,30	31,91	17,65	8,66
Electric Filter or Cyclon	Mio DM/a	-	0,272	0,32	0,022	-	
Scrubber	"	0,76	1,519	0,76	0,054	0,409	0,140
Suction Blower	"	0,38	0,043	0,25	0,0525	0,346	0,140
Reheating Flue Gases	"	0,08	0,508 3)	0,75	-	-	-
Waste Water Treatment	"	0,06	0,233 5)	0,06	0,0455	0,235	0,012
Operating Costs for Flue Gas Cleaning	"	1,28	2,575	2,14	0,174	0,986	0,152
	DM/t	43,40	88,79	44,58	87	96,92	38 4)
related to Overall Operating Costs	%	40,00	28,39	26,97	19,33	19,58	21,71

1) Revenues for steam considered in case of heat recovery

2) including bunker (5 Mio DM)

3) of which 0,476 Mio DM/a are energy costs

4) no costs for neutralization

5) Oxidation of waste water and discharge of a COD-free waste water

3.4.3 Siting problems

The majority of plant operators reported various objections from the local population. In one case dark flue emissions raised opposition, which led to the fitting of an electrostatic filter, while in other cases the smell was found disagreeable when, under certain wind conditions, the waste gas plume was forced downwards. Complaints such as these usually occured shortly after commissioning of the plant and it was found possible largely to eliminate them as the operating personnel gained experience and also by increasing the incineration temperature and the residence time of wastes in the reactor.

The importance of providing the public with information at an early stage is shown by one representative answer which will doubtless meet with general agreement: "Details of the unit and its positive environmental contribution were publicised prior to operation gaining excellent public acceptance".

It is to be expected that such publicity will in future be of increasing significance if planning approval procedures become generally established such as has existed in the Federal Republic of Germany and the United Kingdom for some years.[1] In the former case in the so-called plan approval procedure, the planning documents for the plant are made available for public inspection and also publicly announced and objections from the public are finally discussed with the applicant at special hearings.

This process of public discussion can extend over a period of up to two years or more (in the event of legal disputes) and should therefore be adequately taken into account in the planning of plants for the incineration of hazardous wastes.

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1) Note also: United States are planning license application and approval procedures.

Even if the emission limits laid down by the authorities are met by the application of the latest environmental protection techniques, the possibility still cannot be excluded that as a result of the increased sensitivity of the public in matters of environmental protection - which is to be generally welcomed - the construction of such plants in particular areas may be considerably delayed, made more expensive or, in extreme cases, completely prevented.

3.4.4 Technical difficulties

The principal problems resulting from the chemical properties of wastes were:

- corrosion in the area of the air heater, occasional corrosion in the flue gas channels and on the flue gas gate valves
- corrosion on exposed metal parts, slagging up in certain areas of the combustion chambers, erosion of certain plant components
- corrosion as the major difficulty, overcome by
    - proper mixing of wastes
    - proper selection of protective coatings
    - proper selection of construction materials
- emission of volatile metal compounds and halogens, this has to be controlled by means of composition of the input
- chemical corrosion and thermal erosion pronounced, causing high repair and maintenance costs approximating to 10 - 15 % of capital cost p. a.
- incomplete combustion, overcome by
    - raising operating temperature and
    - increasing residence time by changing position of injection nozzles
- interaction of wastes received, overcome by
    - separate storage facilities and
    - careful pre-screening of wastes received by chemical composition

The essential problems caused by the physical condition of the wastes were:

- caking of easily melting solid substances in the charging area
- plugging of waste injection gun nozzles, overcome by screening to remove solids or even pre-filtration

- unsuitable physical condition for processing as liquid or sludge: the only remaining way is processing as packed waste (60 l drums) or no longer acceptance at plant
- high wear rates on pumps
- suspended solids cause blockages

The problems of a purely technical nature were

- corrosion and erosion of the rotary kiln lining (possible solution: slag analyses)
- dusting up of the boiler
- relatively short life of equipment could be extended by operation at negative pressure and low temperatures (2.000° F) and added safety of operation to personnel
- erosion of lining reduced by filtration and careful quality control of inputs
- slag problems inherent in design overcome by physical removal (pneumatic drill).
- alkaline attack on refractories in General

It emerges from the replies to date that corrosion problems generally represent the main area of difficulty. These can be countered chiefly by

- material analyses
- special cladding of plant components at risk
- mode of operation of the plant
- homogenization of the wastes charged.

3. 5 Detailed description of the Bayer II incinerator system

Appendix IV gives a detailed description of a modern hazardous waste incinerator. Of special interest are the sections dealing with incineration problems with special types of wastes.

4. Co-incineration of hazardous waste with domestic refuse

In certain admittedly limited cases it is possible to treat hazardous wastes in domestic refuse incineration plants. The following sections summarize the replies of the corresponding question 3 in the general questionnaire and the additional information which was received afterwards.

4.1 Amount and types of co-incinerated hazardous wastes

The following table shows the actual state of this disposal method.

Table 22 Co-incineration in individual countries

Country	Number of plants	Addition of special waste (%)	Actual throughput of special waste (t/a)
France	180[1]	≤ 0,1	< 6.500
Great Britain	47[2]	≤ 0,1	
Germany	26[3]	10 - 15	320 - 480.000
Netherlands	11[2]	0 - 10	75.000
Norway	1[3]	0,4	400

In answer to the question concerning these hazardous wastes which were predominantly involved, the following were specified (not in order of significance):

- Waste oil
- Drilling and grinding emulsions
- Emulsions and mixtures of mineral oil products
- Mineral oils, mineral oil sludges
- Mineral oil refinery wastes

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1) incineration units

2) incinerators for household waste in general

3) incinerators which accept hazardous waste in addition

- Grease and wax wastes
- Varnish and paint sludges
- Solvents, solvent mixtures, sludges containing solvents
- Plastics and rubber wastes
- Cellulose production and processing wastes
- Pharmaceutical wastes
- Odorous food and spice processing wastes
- Less toxic burnable industrial waste.

The acceptance for incineration of such wastes represents a service provided voluntarily. It is limited by the spare capacity available as well as by strict environmental protection regulations (for these, see also section 3.6). Since the wastes concerned are predominantly of high calorific value then, especially in the case of older incineration plants, the furnace load may be expected to be the chief limiting factor. Environmental protection legislation varies widely in the participating countries. The above-mentioned special wastes may not therefore be incinerated together with domestic refuse in all countries. Restrictions are possible from case to case.

4.2 Experiences in individual countries

Canada

There is no experience with the co-incineration of hazardous waste and municipal refuse. However, if this was contemplated it would, at present, come under provincial jurisdiction and its environment protection legislation.

France

The concept and operation of an industrial waste incinerator are undoubtedly different from municipal waste incinerators. The latter do not handle hazardous wastes although industrial wastes similar to household wastes may be accepted. Likewise, hazardous waste incinerators in certain exceptional cases could be used for disposal of hazardous wastes.

(Remark: Because of the high operating costs this is only likely to happen in cases of emergency, e.g. during a break down of the local incinerator.)

Great Britain

As far as the legal background is concerned, Great Britain stated that municipal incinerators which, from the nature of the chemical waste co-incinerated, are likely to produce HCl or other emissions of material scheduled under the Alkali Wastes Orders, than the incinerator operation becomes a registered process.

In addition, there are considerable technical problems associated with co-incineration of hazardous wastes, in particular the relatively low temperatures usually offered by municipal incinerators and the means of feeding in the hazardous waste. 15 Waste Disposal Authorities' domestic waste incinerators take very small quantities of special wastes but which are usually not defined.

Since the use of incineration for the disposal of domestic waste is declining, for various reasons, the co-incineration of hazardous wastes is unlikely to increase. As can be seen from table 22 of the report, the amount of hazardous waste added to domestic waste is at present far less than 0,1 %. This may not be true if industrial wastes are added to waste derived fuel, and in fact is not true if we assume leight fuel is in operation.

Norway

In Norway, there are about 50 incinerators for municipal wastes. Many of them are quite small with capacities from 0,5 tons/h and more. Only one incinerator is capable of handling and permitted to handle some hazardous waste. It has an after burner chamber and an electrostatic filter but no scrubbing system and therefore would not be permitted to incinerate halogen containing wastes. Another limitation is the designed thermal load capacity of the furnace. The amount of hazardous wastes incinerated is approximately 400 t/a out of an overall capacity of the facility of 100. 000 t/a.

Netherlands

Co-incineration is now commonly practiced in the Netherlands although the types and amounts are not known. These municipal incinerators which accept chemical wastes are mainly situated in industrial areas.

A rough estimation about the amount of waste co-incineration is shown in table 22, page 71: about 75. 000 t/a of chemical waste (5 % of the total capacity of the municipal waste incinerators) are co-incinerated. This also means that some incinerators accept chemical waste up to 10 % of their capacity.

In the case of co-incineration, the definition of chemical waste or hazardous waste is important. Wastes which have to be considered, in the Netherlands, as chemical waste are not necessarily defined as chemical waste abroad. Experience with co-incineration shows up the possibility of corrosion in heat exchangers, too high temperatures in the case of high calorific value of wastes and, in the case of oil-sand mixtures, mechanical problems with the transport mechanism of the slag, especially with the roller grate system. Experience with emissions is not available.

Because co-incineration concerns chemical wastes, incinerators need a licence under the chemical waste act. Also notification must take place.

The price of co-incineration is of 178,-hfl/t at present (1980).

At this stage, it is not clear what contribution municipal waste incinerators will make to the disposal of chemical wastes. But co-incineration will take place in the future.

Germany

There is little to add to the chapter on co-incineration. Experience in Germany is very similar to that given in the Dutch contribution. Co-incineration is unlikely to play a major role in the future. The reason for this (amongst others such as thermal load capacity, environmental emission standards and additional corrosion difficulties) may be the fact that it becomes progressively more difficult to obtain a licence for the construction and operation of a municipal waste incinerator. In particular, the local population has become very much more sensitive to the siting of incinerators. The community which is in charge of the waste incinerator facility would be ill advised to ask for a licence for incineration of both household waste and hazardous wastes, since they may be running the risk of not to getting a licence at all.

4.3 Some statements on co-incineration

Experience in the participating countries

Experience with co-incineration of household and hazardous wastes varies from country to country. Where incineration of household waste is applied rather extensive than this is true to co-incineration too.

Reasons for a limitation in co-incineration include

- possibility of boiler corrosion because of reducing atmosphere and acid flue gases
- infringement of emission standards
- possibility of exeeding thermal load capacity
- mechanical problems (e. g. feeding system)
- lack of controlling device for incoming waste
- difficulties with licensing authorities or local pressure groups
- bad operational experience

Legal background for co-incineration

In no country are there any special laws and regulations for co-incineration. In general, where stringent environmental protection legislation exists, co-incineration must also meet these standards which may necessitate the introduction of further gas cleaning devices.

Types of hazardous wastes which are co-incinerated

With reference to the list on page 71, all such wastes are the less hazardous industrial wastes which have a high calorific value.

Actual state of this disposal method

Co-incineration of certain hazardous wastes with household waste may be a viable technical option for hazardous waste disposal under restricted circumstances.

Future developments are likely to vary considerably: in some countries the idea of co-incineration of certain hazardous wastes may be promoted officially; in others it will be unlikely to promote or may decline corresponding to a similar development in household incineration. Therefore no general conclusion can be drawn at this stage.

5. Hazardous wastes as a fuel substitute in the cement manufacturing industry

In times of rising fuel prices the use of special wastes as a fuel substitute is becoming an increasingly attractive proposition. In this context it is not only the economic aspect which is of significance: consideration should also be given to the fact that the oil which is thereby saved can be used as a raw material for other purposes. It is, in addition, possible that the noxious substances and residues produced during incineration may be completely bound in special production processes without detriment to the environment or to the product, as in the case of the cement manufacturing industry. This will be discussed in greater detail in a later section.

One question was concerned with the existence of industrial plants in which hazardous wastes were used on an operational basis as a fuel substitute.

When collated, the replies indicated that this occurs chiefly in the chemical industry where non-chlorinated hydrocarbons, waste oil and solvents are used. It emerges that the use of waste oil, acid tars and solvents as fuel substitutes in the cement industry is still in the early stages of development.

The question whether hazardous wastes were also subjected to other methods of thermal treatment (e.g. pyrolysis) was answered with "no" on all the questionnaires so far received. These processes are still at the research stage.

5.1 Fundamental principles

The preliminary stage in the production of cement is the formation of cement clinker. This process in which the finely ground initial materials (raw meal) are sintered into so-called clinker at temperatures up to 1670° K is highly energy intensive.

The cost of fuel accounts for approximately 50 % of the production costs of cement with the result that the use of cheap energy is a fundamental factor in the economy of cement production.

In its chemical composition, cement consists essentially of compounds of silicon, aluminium, iron, calcium and magnesium with the possibility of smaller quantities of other elements. The cement kilns in use today all have a raw meal preheating system, i.e. a device in which the raw meal is heated by direct contact in a counterflow of the hot flue gases from the combustion process.[1] In chemical process terms this means that the gas comes into contact with finely distributed basic material over a wide temperature range and for a long residence time whereby acid constituents of the gas are removed from the gas flow by reaction with the solid material.

The wastes are introduced into the process either with the raw meal or with the fuel. The combustible portion is converted into CO_2 and H_2O with a release of energy, the inert substances present are incorporated into the cement clinker and acid compounds occurring in gaseous form are neutralized by the raw meal and for the most part also incorporated into the clinker.

5.2 Possible special wastes suitable for disposal in the cement manufacturing industry

The principal wastes which are of interest are all those

- which have a sufficiently high calorific value
- whose inert constituents, in the quantities used, have no adverse effect on clinker quality and
- whose volatile toxic constituents can be absorbed by the raw meal and incorporated in the clinker or extracted via a fly ash bypass.

The following types of waste are currently being investigated to establish their suitability for use in the cement production process:

Rubber wastes/old tyres

Waste oil

Acid tars

Halogenated hydrocarbons

Varnish and paint wastes

Bleaching earths

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[1] This is not current for Canada although the number of preheater kilns is on the increase

Sewage sludges

Industrial sludges.

In particular the

- origin
- physical and chemical characteristic values
- occurrence - in terms of quantity and regional distribution - and
- probable behaviour in the combustion process as well as effects on clinker quality and emission

are being determined and compiled.

5.3 Preliminary experiments and results to date

Laboratory experiments

For bleaching earth, acid tars and waste rubber a special experimental programme has been carried out in the Federal Republic of Germany, supported by laboratory experiments and concentrating in particular on clinker quality and the environmental burden to be expected as a result of gaseous and dust emissions.

Clinkers were fired on a laboratory scale from four different raw meals with the addition of ZnO (up to 3 %), PbO (up to 1,2 %), P_2O_5 (up to 1,2 %) and then subjected to both X-ray and mortar analyses.

Results to date demonstrate that the use in the cement kilns of the wastes which have been investigated is, in principle, possible and does not have any adverse effect on the quality of the product. Equally it is not expected that the operation of the rotary kiln will be significantly impaired.

With regard to the ecological burden of gaseous emissions and solid and liquid residues, disposal of wastes in the cement kiln is far superior to all traditional thermal processes. Firstly, the emission levels achieved are, with appropriate operational conditions, lower than those achieved by incineration. And secondly, the typical problems of incineration, such as corrosion, consumption of chemicals and disposal of liquid and solid residues from gas scrubbing do not arise; there is not even any need for final disposal of incineration residues.

From the economic point of view, the cost of alternative disposal and the utilzation of the energy content of the wastes is contrasted with the increased cost of handling in the type of disposal mentioned above. If one considers that, on the one hand, conventional disposal can cost several hundred DM/t and on the other hand, a considerable portion of the primary energy which accounts for around 50 % of the production costs of cement can be saved, then the process may be of considerable economic interest both to the generators of waste and to the cement manufacturing industry.

Field investigation

The use of cement kilns for the disposal of waste liquids was recommended in Canada in 1974 in a report issued by Environment Canada.

An extensive series of experimental waste oil burns were conducted in the spring of 1974. The result demonstrated that the emissions of toxic substances to the atmosphere were negligible and that there were no adverse effects on cement quality. Since cement kilns were located near to urban areas, thus minimizing collection and transportation, the burning of waste oils in such a manner was an acceptable solution to the disposal of waste oil.

In further step the use of the kilns for the destruction of chlorinated hydrocarbon wastes containing up to [illegible] % (by weight) of chlorine was investigated in the U.S. - Canada incineration tests. The waste used included a variety of chlorinated hydrocarbons in a series of programmed phases designed to progress from easily combusted chlorinated hydrocarbons (chlorinated aliphatics) to those which are combusted with difficulty (chlorinated aromatics and alicyclics). The last phase consisted mainly of polychlorinated biphenyl wastes.

During the tests of particular interest, namely the PCB runs, the feed rate of 100 % PCBs waste ranged from about 0,5 kilograms per minute to 6 kilograms per minute and averaged about 3 kg/minute. The actual PCB waste feed was about 50 % PCB content and was burned in conjunction with No. 6 fuel oil being fed at a rate of 20 gals/minute.

The results of the stack gas sampling analyses indicated a minimum combustion efficiency of the waste feed to be 99,986 %. Although traces of volatile low molecular weight hydrocarbons were found (approximately 50 ppb), there was no evidence of the existence of polychlorinated biphenyls at the limits of detection of 3 micrograms per cubic meter. In addition, an increase in particulate emissions ranging from 2 to 4 times the normal rate was observed during the chlorinated hydrocarbon runs.

A mass balance was carried out on chlorine and potassium. This showed that the chlorine input as chlorinated hydrocarbon had completely reacted with the process solids. The alkali content of the clinker showed a reduction which corresponded exactly with the quantity of chlorine input to the system. This agreement further confirms the data from emission testing and the mass balance.

While burning chlorinated hydrocarbons with approximately 40 % chlorine, a decrease in oil consumption equivalent to 65 % of the heat value of the chlorinated hydrocarbons was obtained.

The only differences in the quality of clinker produced while burning chlorinated hydrocarbons were the beneficial effects which were expected through the reduction in alkali content.[1]

It was therefore concluded in early 1976 that cement kilns could be a viable alternative for the destruction of liquid hazardous wastes as described before and in fact an approval or licence was issued to a Canadian cement works. He should be noted that the public had not been informed of these investigations and the positive results achieved. However, when it became generally known that this company was handling PCBs, the public reaction was swift and intensive and finally so effective that the company voluntarily surrendered back its licence for PCB disposal to the provincial agency and therefore at present no PCBs are burnt.

The Canadian experience with the use of cement kilns has spanned five years. It has proved that cement kilns represent an environmentally secure system for the destruction of liquid chlorinated hydrocarbons if they are properly equipped, operated and regulated.[2] But it has also shown that introducing a new waste disposal method for hazardous wastes means involving the public at an early stage of the development, so that its concern could be recognized and the relevant problems solved in a rational and scientific manner.

6. Incineration of selected wastes (PCB, mineral oil wastes)

The following chapter deals with two selected kinds of wastes: PCBs and mineral oil wastes. PCBs are of major interest because of their toxicity and the fact that little is known about their current disposal methods whereas mineral oil wastes represent quite a large amount of all special wastes incinerated.

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[1] These effects do not necessarily have to be beneficial. This depends on the composition of the raw material. E. g., in Norway and in some parts of Germany the alkaline content is rather low and the possibility of burning high chlorinated hydrocarbons is very limited.

[2] Sweden has run similar tests on incineration of PCBs in cement kilns and has come to the same conclusions. With a detection limit for unburnt PCB of 0,[illegible] mg/kg PCB fed to the [illegible], no PCB was detected in the effluent gas stream. This represents a destruction efficiency of more than 99,[illegible] %. Source: Institute for Water and Air Research, Stockholm.

6.1 Incineration of polychlorinated biphenyls (PCB)

Polychlorinated biphenyls (PCB) are a mixture of compounds with chlorine contents varying between 30 and 60 % which is difficult to separae.

While the more highly chlorinated biphenyls involve the danger of chronic poisoning or widespread environmental contamination, the risk atached to the PCBs with a lower chlorine content is their acute toxicity. The danger is increased by the fact that PCB is often contaminated with other substances which are even more toxic.

The results of PCB poisoning are, initially, alterations to the skin, chloracne, darkening of the pigmentation, and damage to the internal organs. Harm to the foetus in the womb (as found in Japan) is highly significant. PCB is listed in the Maximum Working Site Concentration (MAK) list 1977 under substances suspected of having a significant carcinogenic ptential and requiring urgent further study.

PCB was first produced industrially in 1930. Since then approximately 1 million tons of PCB have been produced around the world. Origially, PCB was chiefly used in

- the electrical industry as a non-combustible insulating and cooling medium for transformers and capacitors,
- paint and plastics engineering as an alkali-proof and acid-proof plasticiser,
- constructional engineering as hydraulic oil (flame proofed) and heat exchange liquid,
- the paper industry (e.g. carbonless copying papers).

In the USA and Japan, domestic refuse incineration plants have also been recognized as sources of PCB emission. According to available information f[illegible] the USA, on average 0, 4 mg PCB volatilizes per cubic meter of flue gas. At four domestic refuse incineration plants in Aichi (Japan) figures of 0, 32 to 1, 35 mg PCB per cubic meter of flue gas were measured. In the Federal Republic of Germany no such measurements have as yet been carried out. However, ist is planned co make the first survey of PCB emissions at the domestic waste incineration plant in Wuppertal within the framework of a research project dealing with the optimization of a separating device to prevent the emission of harmful constituents from refuse incineration plants, as well as the conduct and evaluation of a programme of measurement especially for PCB and heavy metals". Results were expected by the end of 1979 but were not available at the deadline of this report. According to estimates based on analyses of the PCB content in domestic refuse in 1973, PCB concentrations of up to 0, 4 mg per cubic meter of flue gas (before any flue gas cleaning procedure) can be expected.

6. 1. 1 Legal situation

The Directive of the Council of the European Communities of 6th April 1976 concerning the disposal of polychlorinated biphenyls and terphenyls (Official Gazette of the European Communities No. L. 108/41 of 26. 04. 1976) is aimed specifically at environmentally compatible disposal of residues containing PCB/PCT, e. g. Article 6: "For the application of Articles 2, 3, 4 and 5 the responsible authorities in the member states shall establish the plants, installations or enterprises approved for the disposal of PCB ....".

Such plants, installations or enterprises have not as far been named. In corresponding regulations in the Federal Republic of Germany it is laid down that polychlorinated biphenyls (PCB) or substances containing PCB may be incinerated only in plants specially suited to that purpose. There are as yet no precise regulations concerning the equipment for such a plant and the technical procedure to be followed.

In the same regulations PCB is classified in Category I of harmful constituents which means that in a mass flow of 0, 1 kg/h not more than 20 mg PCB per cubic meter of flue gas may be present. Furthermore, it is laid down that a minimum temperature of 1200° C must be reached in the afterburner before PCB wastes may be introduced into the incinerator chamber itself.

In the United States regulations for disposal of PCBs under the Toxic Substances Control Act (TSCA) are now in effect. Incinerators for PCBs have to meet the following requirements :

1. Liquid PCBs

Combustion criteria shall be either of the following:

- maintenance of the introduced liquids for a 2-second dwell time at 1. 200° C (± 100 ° C) and 3 % excess oxygen in the stack gas or
- maintenance of the introduced liquids for 1 1/2 second dwell time at 1. 600° C (± 100° C) and 2 % excess oxygen in the stack gas.

Combustion efficiency shall be at least 99, 9 %
Destruction efficiency shall be at least 99,9999 %
Measuring and recording of rate and quantity of PCBs fed to the combustion system, of the temperatures, of stack emissions (O_2, CO, CO_2, NO_x, HCl, total chlorinated organic content, PCBs, particulates)
Automatic stop of the flow of PCBs to the incinerator in case of failure of the water scrubbing system for HCl. An alternative method of HCl control may be used if such a method has been approved. The HCl neutralizing capability of cement kilns is considered to be an alternative method.

2. Non-liquid PCBs

The mass air emissions from the incinerator shall be not greater than 0, 001 g PCB/kg of the PCB introduced into the incinerator.

The incinerator shall comply with all provisions mentioned under 1. except combustion criteria.

All PCB incinerators must be approved. To date, [illegible] incinerator has been licensed.

In Norway in November 1979 regulations were issued concerning PCBs which went into effect on January 1st, 1980. Chapter 7 "Treatment of hazardous wastes" lays down that such waste must be delivered to an officially approved receiving site for hazardous wastes or has to be dealt with in another manner approved by the State Pollution Control Authority. The comments to the regulation add that incineration or regeneration are methods which could be applied. In 1979 and 1980, a number of officially approved receiving sites for hazardous wastes will be established in this country.

In the United Kingdom positive guidelines for the incineration of PCB's are given in the Department of the Environment's Waste Management Paper "Polychlorinated Biphenly (PCB) Wastes"

6.1.2 Thermal destruction of PCB

References to thermal treatment are given in many publications. In these, a minimum temperature of 800° C is taken as a prerequisite for the destruction of PCB. In the USA the EPA in 1977 commissioned high-temperature analyses on a laboratory scale. The experiments with individual PCBs showed that biphenyls having both high and low chlorine contents were not destroyed in the temperatur range below 560°C. For example, even at a temperature of approximately 700° C and with a residence time of 1±0,1 second, decomposition rates for tetrachlorobiphenyl, of only around 81 % and for decachlorobiphenyl of only around 64 % were attained. At temperatures above 800° C all PCBs except decachlorobiphenyl were completely destroyed and the quantity of decachlorobiphenyl subsequently detected was less than 0,1 % of the quantity introduced.

In a second set of experiments the individual substances - with biphenyl as a control - were incinerated at a constant temperature of 704° C and with differing residence times. After a residence time of almost four seconds, decomposition rates of [illegible] % (biphenyl) down to approximately 84 % (decachlorobiphenyl) were attained.

In a third series of determinations with a mixture of various chlorinated biphenyls at a temperature of 1000° C and a residence time of one second, a decomposition rate of 99, 995 % was achieved, and with a residence time of two seconds a decomposition rate of 99, 9995 % was attained.

The results of these investigations can be summarized as follows:

- PCBs with low molecular weights have lower thermal stability than PCBs with high molecular weights.
- The two most important factors influencing the thermal treatment of PCB are temperature and residence time, which are themselves interrelated, i. e. if the temperature is increased the residence time can be shortened.
- Below 560° C, PCBs are not destroyed.
- At temperatures above 1000° C a decomposition rate of over 99, 9 % can be expected.

In qualification it should be noted that the experiments were carried out with pure PCBs, and the behaviour of PCB when incinerated in a mixture with other wastes such as domestic waste or waste oil was not investigated. Furthermore, the effect of a scale increase from laboratory apparatus to an operational plant must be taken into account, since for this reason, somewhat higher temperatures and/or longer residence times should be used in large-scale continuous operation.

As previously stated, little is known about the currently practiced disposal of used PCBs. It may be presumed that PCB is currently disposed of either with waste oil or, in some cases, by incineration at sea. In the United Kingdom and the Federal Republic of Germany incineration of PCBs is carried out in altogether three major industrial waste incinerators, involving the sole producers (now no longer manufacturing PCBs in the UK). In all cases results showed that destruction was substantially complete under the operating conditions of the incinerators.

6: Incineration of mineral oil wastes

The following information was provided by the participating countries:

Norway: Norway does not regard waste oil (used lubricants) as waste. There is a market for waste oil. Annually some 20.000 t are collected or mixed with fuel oil and 5.000 t are regenerated. These figures are included in table 1, page 12 of the report. The total amount of used lubricants is about 50.000 t/a. Acid tar (700 t/a) and water-, oil- and sand-mixtures (5.000 t/a) are not treated prior to final disposal, whereas out of 3.000 t/a grinding emulsions 1.000 t/a are treated by emulsion separation.

Canada: Most of the waste oil is not incinerated at hazardous waste incinerators but is used for road oiling, fuel in cement kilns or retained by the generators to be used as supplementary fuel at their facilities.

France: The present French regulations do not allow incineration of waste oil as long as it can be regenerated. Oil which does not meet the demands for regeneration may be incinerated in authorized facilities.

Great Britain: There are two general methods of disposal: namely incineration and disposal to land with the former as the preferable method in many cases. At present about 200.000 t/a are incinerated. Often the waste may have some value at a central disposal facility where admixture with other wastes requiring disposal by incineration may reduce fuel costs. On the other hand, mineral oil wastes of low calorific value and varying composition become increasingly more expensive to dispose of by incineration.

In general, municipal incinerators have not been designed for the handling of mineral oil wastes as feedstock but it may be possible, subject to the constraints imposed by design considerations, to incinerate limited quantities (1 to 2 %) of certain oil wastes, for example sludges, acid tars and spent clay in admixture with domestic waste. Facilities to incinerate most oil wastes are available through the private sector.

Acid tar sludges can be incinerated in special plant equipped with suitable burners or otherwise capable of accommodating the drummed waste but the handling of these corrosive materials and the treatment of the highly acidic combustion gases present added difficulties.

Incineration of spent clay either alone or uniformily mixed in a given ratio with domestic waste is possible but landfill is normally employed.

One particular method for leaded sludges (from gasoline storage tanks) is incineration at greater than 400°C in a suitable incinerator after removal of supernatant liquid, which may contain petrol.

Besides recovery, use as a supplementary fuel in suitably equipped installations is a possible disposal procedure for the following wastes:

- spent motor oils
- non-emulsified oil mixtures
- oil wastes and oily sludges
- oil containing residues
- acid tar sludges after suitable pretreatment.

One condition for a wider use is improvements in incinerator design to improve the capability for handling wastes of varying calorific value. All incinerator emissions should comply with requirements under the appropriate legislation.

Netherlands: Waste oil treated thermally

Application as	t/a
bunker fuel[1]	40.000
substitute fuel	60.000
Total	100.000

Regulations for waste oil are given in special paragraph (the so-called oil paragraph) in the chemical waste act.

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[1] blending with bunker fuel for improving viscosity

Germany: The following figures are based on the results of a working group "mineral oil containing residues" which has been set up to update a similar report of 1975.[1)]

The residues were broken down into the following categories:

- waste mineral oils
- oil emulsions and oil mixtures
- mineral oil sludges
- acid tar and acid resins
- mineral oils containing spent clay

The amount of waste mineral oils (with maximum 10 % impurities) was about 433.000 t in 1977. Besides reclamation as lubricant by commercial recovery firms, incineration is a common method of disposal to utilize the energy content (>30.000 kJ/l) of the waste.

As a fuel substitute it may be used the following way:

- in power plants to generate electricity or steam for district heating or industrial use
- in pig-iron production
- in cement works
- in municipal waste incinerators
- in hazardous waste incinerators
- in sewage sludge incinerators.

In 1977 the amount incinerated was about [illegible] %. Since 1972 (33,5 %) this figure is declining. The reasons are increasing amount of reclaiming (sponsored by federal grants) and more intensive controls of incinerator facilities.

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1) Materialien zum Abfallwirtschaftsprogramm '75 der Bundesregierung - Mineralölhaltige Rückstände - Stand November 1979, Umweltbundesamt, Materialien 2/80, Berlin 1980

It is often suggested that the reclamation of waste mineral oils is a preferable option to incineration. However, theoretical studies in the U. S. have shown (from the energy balance point of view) that this is true only if waste mineral oils are treated prior to combustion. If they are not and if long distance transportation to centralized secondary refineries is involved or pretreatment costs are high (e. g. elimination of impurities, amongst others approximately 15 % waste water) then the favorable balance may be overturned.

Another possibility is the use of waste oils as a fuel substitute in cement works and in bitumen manufacturing where the final product can incorporate impurities from the fuel. In 1977, the quantity of oil emulsions approximated to 300. 000 t and oil/water emulsions to 1, 5 M t. Incineration of this kind of waste does not yet play an important role. However, it is pointed out that incineration in municipal waste incinerators could be of interest especially to lower the heat transferred per unit surface. For the complex compounds which are difficult to crack, hazardous waste incinerators are more suitable.

Another disposal method of interest is the addition of oil/water mixtures (impurities~70 %) to the coal ($<$1 %) prior to degasifying in a coking plant. With a residence time of 18 to 24 hours and a temperature of more than 1. 000° C a total destruction of all compounds is achieved.

The material "mineral oil sludges" is somewhat difficult to define. It consists mainly of mineral oil, specific solids and probably water and/or other liquids and could have a wide viscosity range. These wastes approximated to 113.000 t in 1977 and (because reclamation is not of much importance) are mainly disposed of in waste oil incinerators or hazardous waste incinerators. Depending on local conditions incineration in municipal waste incinerators may be possible. Fluid mineral oil sludges with a high halogen content (e. g. chlorine) are incinerated at sea.

It is estimated that in 1976 about 29.000 t of acid tars occured of which about 3.500 t were incinerated. Because of changes in production methods the amount is decreasing and for 1980 approximately 9.000 to 10.000 t of acid tars are expected to arise. The amount of acid resins was about 37.000 t in 1977 of which about 13.200 t were incinerated and about 3.300 t were charged into cement kilns (amount increasing). If they are incinerated, the flue gases contain a high portion of sulphur dioxide which is harmful to the environment and is there fore unilikely to be permitted without adequate control systems. Several incineration facilities for acid resins were closed down in the past because of failure to meet emission standards.

Some research work is recently underway to determine whether pyrolysis could be applied to acid resins in order to produce sulfuric acid or gypsum.

In 1976 the amount of bleaching earth waste was about 38.000 t. In addition to chemical landfill and co-incineration with municipal waste the use of this waste as flux material mainly in cement works and brickworks becomes a more interesting possibility. In 1978, 80 % of bleaching earths from primary refining and 68 % of bleaching earths from secondary refining were used this way, which does not produce any environmental problems.

United States of America: Generation and disposal of used lubricating oils: It is estimated that approximately 1,4 billion gallons of used lubricating oil is generated anually in the U.S. The disposition of this oil is:

	Gallons
Burned as fuel	700.000.000
Road Oiling	200.000.000
Used in rerefining	100.000.000
Other disposal (not determined)	
Landfilling	400.000.000

It should be noted that do-it-yourselfer engine oil sales have increased from an estimated 20 % to 50 % of sales since 1974. Much of this oil is not recovered and it is difficult to determine its fate. Therefore the estimates above are not precise.

Used oil burned as fuel: Data are not available on the distribution of used oil burned as fuel. It is, however, reasonable to assume that a greater portion is used in large boilers which burn residual fuel. Used lubricating oil can be, and is, mixed with distillate fuels, No. 1 and No. 2. As far as is known this occurs when fuel oil distributors mix the used oil with the virgin fuel oil. It is also known that smaller users of fuel such as greenhouses and apartment buildings purchase used oil for boilers. Little information is available for such consumption.

However, it is reasonable to assume that of the 700 million gallons estimated to be used as fuel the following breakdown is lekely:

a) used as fuel for large boilers	240. 000. 000 gallons
b) used as fuel for small boilers	280. 000. 000 gallons

The best estimate for on-site use of waste oil would be that not more than 10 % or 70. 000. 000 gallons are burned on-site.

Effect of government policy, laws and regulations on recycling of used oil: The Excise Tax Reduction Act (1965) plus FTC labeling requirements, restrictions against use of re-refined oil by the military, as well as problems of rerefinery waste disposal, reduced the production of rerefined oil from approximately 300 million gallons in the early 1960's to 51 million gallons in 1975. Further, since the oil embargo of 1973 and early 1974, the price of fuel oil has increased to the point that the rerefiner and reprocessor cannot compete for the used oil feedstock. This, therefore, has resulted in a situation where most of the used oil collected is entering the fuel and the road oiling markets.

Efforts are underway to remove some of the above barriers to re-refining. In addition, the U. S. Department of Energy has developed a new oil re-refining process which should improve the economic viability of re-refining and reduce the problems of waste disposal. Nevertheless, the increasing prices for petroleum are likely to continue to raise the market value of waste oil used as a fuel so that its use in that application will continue to dominate.

Air pollution regulations naturally impact on the use of oil as a fuel. Oil from industrial sources can contain heavy metals. However, there are currently no standards for most heavy metals. Lead is an exception. EPA has established ambient air quality standards for lead. This impacts particularly on burning of automobile lubricating oil which picks up lead from leaded gasoline. However, the impact of this standard on burning of waste oil is not likely to be major. The air standards will impact primarily on larger new boilers and much waste oil will be burned in existing boilers. Finally the lead content in gasoline is decreasing rapidly as use of leaded gasoline is phased out.

EPA's hazardous waste regulations could significantly impact on waste oil disposition. In the proposed rules promulgated on December 18, 1978 for comment, waste oil was listed as a hazardous waste. Waste oil which is re-refined was exempted from controls under the regulations but all other disposition of oil was covered, including use as a fuel. A large number of commentors objected to the inclusion of oil burned as a fuel. After review of the environmental issues, the EPA is considering also exempting oil burned as a fuel from the hazardous waste regulatory controls. Reasons for this would be the fact that standards already exist to deal with the lead emission problem and that problem is declining. Furthermore, although there are no air standards for most of the metals found in industrial oils, a comparative analysis of No. 6 bunker oil with waste industrial oils show similar levels of metallic contaminants.

If oil burned as a fuel is included in the hazardous waste regulatory system, it will greatly reduce oil burning and enhance re-refining. If waste oil burned as a fuel is exempted, the burning of waste oil should expand.

7. Incineration of hazardous wastes at sea

The wastes to be considered here are predominantly liquid chlorinated hydrocarbons which may contain oxygen, nitrogen or sulphur as well as other halogens such as fluorine, bromine and iodine. The wastes occur both in the production and further processing of chlorinated hydrocarbons.

7.1 Fundamental principles of the incineration of chlorinated hydrocarbons

The process conditions in advanced firing equipment ensure almost complete combustion of chlorinated hydrocarbons. Apart from the nitrogen and the residual oxygen of the combustion air, the flue gases contain CO_2, H_2O, HCl and Cl_2 as products of combustion. Traces of inorganic substances (amongst others, heavy metal compounds) present in the initial material also recur in the products of combustion. The quantities of CO and unburnt waste depend on the completeness of combustion.

The ratio of $HCl : O_2 : H_2O : Cl_2$ is determined by a temperature related equilibrium constant so that the proportion of the individual constituents in the flue gas mixture can be correspondingly influenced. To simplify flue gas treatment,as low a chlorine content as possible is aimed at. This can be achieved by the use of high temperatures with relatively little excess oxygen. Furthermore, a high water vapour content of the flue gas favours the desired objective of HCl formation at the expense of the Cl fraction. Injection of steam or water is sometimes used to ensure sufficient H_2 for complete conversion to HCl.

With a calorific value of the waste of 10.500 kJ/kg or more independent combustion is possible corresponding to a chlorine fraction of approximately 70 % by weight.

Too low a calorific value of the waste can be compensated for by the use of additional fuel. If the waste and additional fuel is present in the same state of aggregation then preliminary mixing is possible and advantageous. So-called high-speed burners have proved to be an advantage as incinerator devices for chlorinated hydrocarbons.

7.2 Possibilities and limits of incineration in land-based plants

The incineration of chlorinated hydrocarbons in plants on land requires two basic elements: an incinerator installation with an afterburner and, in order to meet emission standards, a flue gas scrubbing plant.

The incineration processes used ensure that at least 99,9 % of the chlorine content of the wastes is converted into HCl. Combustion residues occur as flue gas, constituents of the flue gas scrubbing effluent and also as solid residues (on the port blocks and the dividing walls of the firing equipment). The scrubbing effluent contains, apart from absorbed HCl, neutralizing agents (e. g. NaOH), the salts produced by the neutralization reaction (e. g. NaCl) and dissolved solids. The greater portion of the heavy metal constituents of the original wastes generally occurs in these solids.

The treatment of this effluent and the resulting sludge residue is very expensive and fraught with operational and sewage treatment management problems.

The capacity of the flue gas scrubbing plants linked to the existing land-based incineration plants only permits the incineration of low-chlorine hydrocarbons (10 - 25 % by weight Cl) and only when mixed in relatively small proportions with other chlorine-free liquid wastes. Furthermore, the use of chlorinated hydrocarbons as additional fuel in the afterburner chambers is energy saving and free of corrosion problems only in the case of low-chlorine substances.

A survey carried out in Germany in 1977 showed that in only four out of 13 special waste disposal plants questioned were chlorinated hydrocarbon wastes incinerated,and in those the total volume was of the order of 30.000 t/a.

In any case on the question of treatment of chlorinated hydrocarbons it should be demonstrated whether any recycling/regeneration method could be applied as an alternative to incineration. At present, there exist the following possibilities/techniques:

1) incineration with retrieval of HCl in the production line
2) chlorolysis
3) selective reconditioning

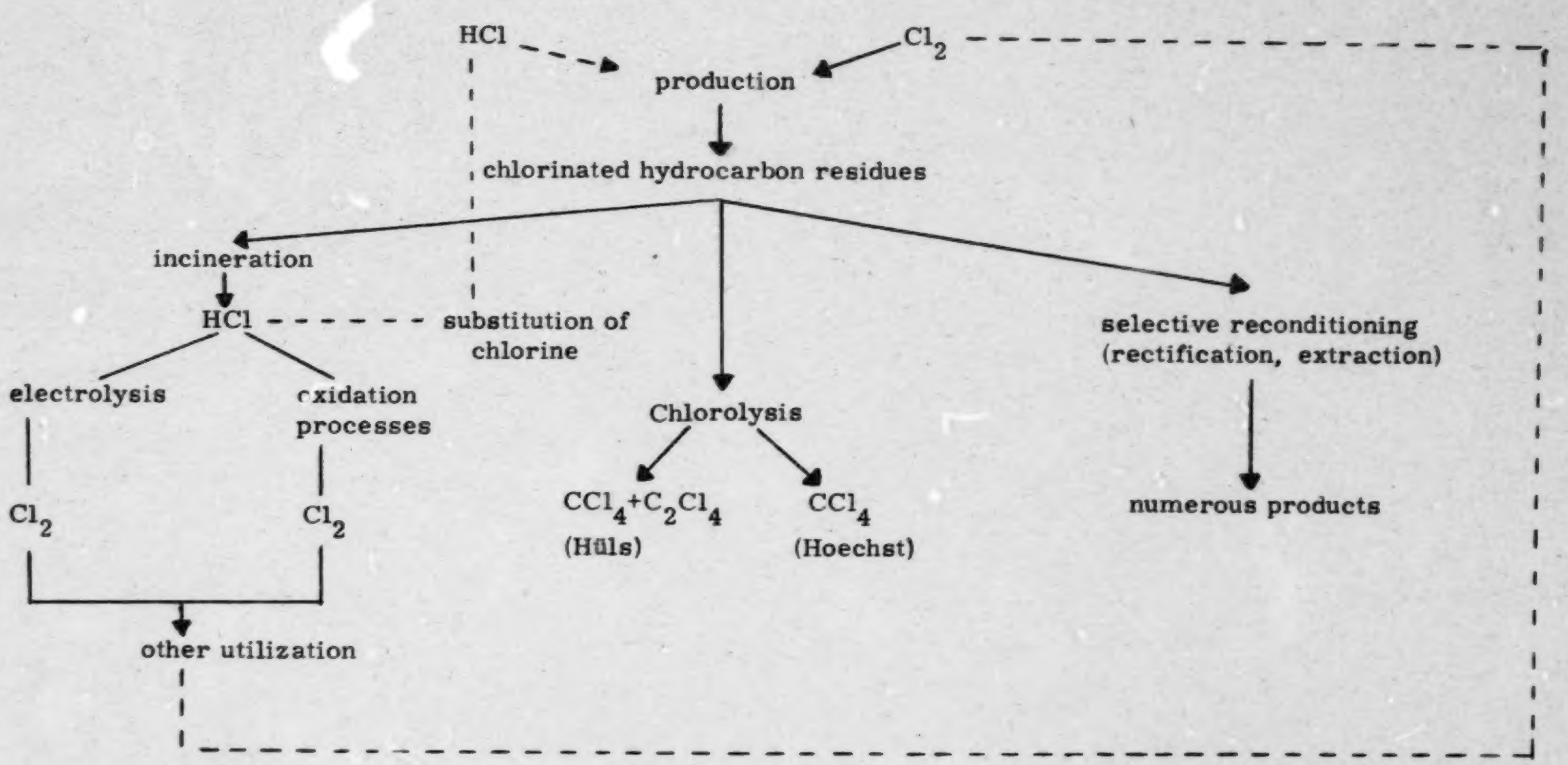
Figure 2 gives a rough overview.

Item 1: The hydrogen chloride resulting from incineration may be used for chlorine production. Different methods may be applied, e. g. electrolysis of hydrochloric acid or chemical processes. Another possibility is to use the hydrogen chloride as a direct substitution for chlorine in the chlorination of hydrocarbons.

Item 2: By means of chlorolysis chlorinated hydrocarbons are used as "raw materials" to produce other substances. In some cases these processes do not generate any other new waste.

Item 3: In practice, numerous processes are known for the selective recovery of liquid chlorinated hydrocarbon residues such as rectification and extraction. With the aid of these separation methods, a variety of components can be isolated. However, the economics of these processes ist likely to render them uncompetitive.

Figure 2 Regeneration possibilities for chlorinated organic residues


HCl
Cl_2
production
chlorinated hydrocarbon residues
incineration
HCl
substitution of chlorine
electrolysis
oxidation processes
Cl_2
Cl_2
other utilization
Chlorolysis
$CCl_4+C_2Cl_4$ (Hüls)
CCl_4 (Hoechst)
selective reconditioning (rectification, extraction)
numerous products

7.3 Incineration of chlorinated hydrocarbon wastes at sea

The essential difference between incineration in landbased plants and on ships at sea lies in the way in which the combustion products leave the plant. In the case of incineration systems at sea untreated combustion products escape directly into the atmosphere where they are distributed in the air and water.

It is claimed that incineration at sea is an environmentally acceptable method of disposing of chlorinated hydrocarbons for the following reasons:

- incineration at sea has to be carried out at an appropriate distance from the coast,
- owing to its high chloride concentration, sea water provides an excellent reservoir for the acceptance of inorganic chlorides produced during incineration
- since sea water has a considerable buffer effect it is able to neutralize HCl without changing its pH
- owing to the absence of problems associated with the disposal of scrubbing effluent, incineration at sea can dispose of chlorinated hydrocarbon wastes more effectively and quickly than landbased incineration.

Disadvantages of incineration at sea:

- the destination of the clouds of flue gas (especially the HCl) and the transition into the sea water cannot be completely monitored,
- considerably greater safety precautions and measures for malfunctions or accidents are required than in the case of landbased incineration,
- incineration at sea offers no possibility of recovering raw materials from the combustion products,
- additional risks in transporting these wastes over long distances (either by rail or by ship) to the incineration vessel and the transshipment of the wastes in the harbour.

7. 3. 1 Test burns on board the M/T Vulcanus[1)]

Since the M/T Vulcanus began incinerating chlorinated waste in 1972, the governments of France (1974), the Netherlands (1974) and the United States (1974, 1977, 1978, 1979) have carried out tests on board to ascertain the combustion efficiency in the two incinerators.

What follows below is a summary of the results of the tests together with a rundown on the relevant test reports. The French government carried out a preliminary test on incineration on board the M/T Vulcanus in 1974. The conclusion was that the stack gases of the Vulcanus contain a quantity of unburnt compounds in the order of 0, 5 ppm. Chlorinated aliphatic wastes were the main substances incinerated (mainly 1, 2 dichlorethane).

In the Netherlands a preliminary test was performed into the combustion efficiency of a so-called EDC-tar (a waste comprising 68, 3 % chlorine which is produced in the manufacture of vinylchloride). The finding was that the combustion gases contained only small amounts of organochlorine and organobromine compounds in the order of 20 - 45 mg Cl/m^3 which corresponded to a combustion efficiency of more than 99, 9 %. The presence of methylene chloride, chloroform, carbon tetrachloride, carbon and dichloro-dibromomethane was established with certainty but it was not possible to carry out an extensive quantitative analysis of the stack gases.

Preliminary tests were also carried out in the United States in 1974 with comparable wastes which mainly comprised chlorinated aliphatic compounds. This test revealed that with flame temperatures of between 1. 310° C and

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1) The following overview is taken from the paper "Certificate of approval and survey report on the M/T Vulcanus", pp. 13 - 15, presented by the Netherlands at the sixth meeting of the "Working Group on Incineration at Sea" under the "Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft" (Oslo-Convention), held from May 20 - 22, 1980 in Paris. The literature this report refers to is included in the references.

1.610° C in the furnace, the combustion efficiency was between 99,92 and 99,98 % while the figure for the destruction of organochlorine compounds was on average 99,95 %. During a second study with the same type of waste, 99,95 % combustion efficiency was recorded in 1977.

Again in 1977 a study was carried out in the United States during the incineration of so-called Herbicide Orange by the M/T Vulcanus. This waste contained equal quantities of the n-butyl esters of 2,4-D and 2,4,5-T (2,4 dichlorophenoxy acid and 2,4,5 trichloro-phenoxy acid) and contained the highly toxic 2,3,7,8 tetrachloro-dibenzo-p-dioxin (TCDD) as an impurity on average of 2 ppm.

During these incinerations the Herbicide Orange was destroyed with more than 99,99 % efficiency. The figure for the TCDD was 99,93 % and that for the entire waste (the conversion of the organic material on the basis of the CO and CO_2 content in the combustion gases) was 99,99 %.

In 1979 the U.S. Environmental Protection Agency also commissioned an evaluation of the equipment for routine sampling and analysis of CO and CO_2 in the combustion gases, when combustion efficiency figures of more than 99,96 % were recorded.

7.3.2 Volume of waste incinerated

Since 1969, the following volumes are estimated to have been incinerated at sea:

1969	4.000 t/a
1970	8.000 t/a
1971	28.000 t/a
1972	66.000 t/a
1973	87.000 t/a
1974	100.000 t/a

1975	85. 000 t/a
1976	85. 000 t/a
1977	60. 000 t/a
total	523.000 t

Other estimates give 586.000 t as having been incinerated between 1969 an 1978.

The highest annual quantity of these wastes originating in the Federal Republic of Germany was of about 80. 000 t.

Three main reasons may be cited for the decline of waste since 1974 (no estimations were available for 1979):

- decreasing amount of waste being delivered for marine incineration due to increased energy costs.
- taking out of service of some incineration vessels (see below) because of uneconomical running of these ships
- increasing amount of waste being regenerated.

It should be noted that the Dutch AKZO company is operating an HCl-regeneration plant for 8. 000 t/a of its own chlorinated wastes and 15 - 20. 000 t/a of waste from other companies in the Netherlands. In the past these waste streams were incinerated at sea.

7. 3. 3 Equipment and mode of operation of the incineration ships

Since 1969, the incineration ships listed in table 23 have been in service predominantly in the southern North Sea.

Owing to unseaworthiness and inadequate monitoring and control systems, the Matthias I has been laid up. The Vulcanus is currently being given a major overhaul and brought up to the latest technical standards. The Matthias III was in service for only a short period, but owing to the sharp decline

Table 23 Incineration vessels for liquid chlorinated hydrocarbons

Ship	Owner/ Operator	Start of service	Size in GRT	Length/ beam in m	Incineration units	Burner per unit	Incineration capacity t/h	Incineration capacity t/a	Hold tanks number	Hold tanks overall capacity m^3
Matthias I	Industrieanlagen-Verwaltungsgesellschaft Oberursel-Weißkirchen mbH; for Matth. II since July 1979: Wulf GmbH & Co. KG für Abfallverbrennung auf See, Essen	1969	438		1	6	3 - 6	15.000	6	550
Matthias II		1972	999	72,3/ 10,8	1	8 + 4	10 - 12	60.000	12	1.200
Matthias III		1976	12.636	176,5/ 21,5	1	20	20 - 40	150.000	9	15.000
Vulkanus	Ocean Combustion Service BV/Rotterdam (OCS)	1973	3.098	102,0/ 14,4	2	3	20 - 25	100.000	15	3.500
Vesta	Lehnkering AG, Duisburg	1979	999	71,8/ 11,0	1	3	ca. 10	50.000	8	1.400

in the supply of waste it was according to the operator uneconomical to run the ship. It was therefore sold for scrap. Despite this, a new incineration ship, the Vesta, was built in the Federal Republic of Germany and is in service. In the U. S. it is known that one company (Global Marine) is investigating the possibility of refitting a surplus tanker as an incinerator ship with a capacity of 12.000 t. Also, the U.S. EPA and the U.S. Maritime Administration are working jointly to develop a U.S.-based incineration ship.

Incineration ships are converted or newly designed double-hulled tankers (complying with the IMCO code on the transportation of poisonous chemicals) which, in some cases, can still maintain incineration in force 9 winds.

The mortar-like incineration furnaces are arranged vertically up to 16 m high in the bow or stern of the ship. The top of the furnace is open so that the flue gas escapes directly into the atmosphere. The Matthias I, II, III and the Vesta each had one furnace and the Vulkanus has two furnaces arranged side by side. The furnaces are equipped with special lining and special burners. The liquid wastes are atomized and injected into the incinerator chambers by means of compressed air, where they burn at temperatures above 1.470° K. Only when a certain minimum temperature has been reached, is firing switched from oil to liquid wastes.

The hold tanks of the ship can be emptied only via the burners so that it is impossible for waste to be dumped at sea.

On-board control systems ensure that important data such as the incineration temperature and location of the ship are continuously logged and can be made available to the appropriate authorities.

For the purposes of licensing by the appropriate authorities of the contracting states, the equipment and operational organization of the ship must meet the "Technical Guidelines on the Control of Incineration of Wastes and other Matter at Sea" of the London Convention.

7. 3. 4 Technical guidelines of the Oslo and London Conventions

Special guidelines have been drawn up by the contracting states to the Oslo and London Conventions on the prevention of pollution of the sea by the discharge of wastes. The aim is to subject the incineration of wastes at sea to certain requirements including adequate monitoring to ensure that no detriment is caused to the maritime environment by the combustion products and the unburnt residues and that the basic requirements laid down in the Conventions are met.

The technical guidelines are based essentially on the following requirements:

Equipment, approval and monitoring of the incinerator installation

- The volumes of waste and additional fuel must be continuously measured and the measurements recorded.
- The volume of air fed into the incinerator installations must ensure adequate excess oxygen (≥ 3 %) in the flue gases; the oxygen content of the flue gases must be recorded.
- Combustion must take place at at least 1. 470° K. The temperature at which waste charging is to be automatically stopped is 1. 370° K. Temperature measurement must be made by thermocouples in the furnace wall. The number and type of thermocouples and their installation locations must be laid down.
- A residence time of the combustion gases of at least one second at 1. 520° K must be guaranteed.
- The combustion efficiency must be at least 99, 9 %. Control of this must be ensured by measurement and recording of the CO_2 and CO contents and in addition the O_2 content.

Essential monitoring of the incineration ship and its operation

- Liquid wastes must not be taken on outside harbours.
- It must be impossible for the liquid wastes to be emptied out of the hold tanks of the ship except via the furnace burners.
- Solid combustion residues must not get into the sea water or be disposed of at sea.
- The operation of the incineration ship must not jeopardize other shipping.
- The incineration ship must comply with the IMCO code for the construction and equipment of ships for the transportation of hazardous chemicals.

Monitoring of the type and volume of wastes to be incinerated

- The type and volume of wastes must be known before acceptance by the incineration ship and described in detail in the course of the approval procedure.
- Sample analyses must be made of the wastes delivered.
- It must be established that certain contaminants in the waste and unburnt remains of the initial materials do not exceed the trace level.
- Wastes over which doubts exist as to the efficiency of combustion must undergo special test procedures.

Selection of the incineration area

The following must be ensured:

- adequate distance from coasts and adequate depth of water,
- favourable atmospheric conditions, i.e. favourable prevailing wind direction and relatively high mean wind speeds,
- relatively little use for fishing purposes,
- no detriment to fishing grounds, spawning grounds and breeding grounds,
- low level of shipping,
- little ore, oil or natural gas extraction activity or prospects,
- no military operations,
- no detriment to telecommunication cables and pipelines,
- no effect on the routes taken by sea birds or migratory birds.

7.4 Present state of discussion

Two tendencies appear in the discussions: on one hand the waste generators look at incineration at sea as a possible disposal method which produces only anegligibly low residual pollution if it is done under strict control; alternatively, with reference to qualitative and quantitative alterations in and around supervised (controlled) discharge areas, incineration at sea is only regarded as an intermediate solution until technically and economically improved methods for disposal on land are developed. In any case the practical availability of alternative landbased methods of disposal, elimination or of treatment to render the wastes less harmful should first be considered. The contracting states to the 1972 Oslo and London Conventions tended to the latter view and agreed that the regulation of incineration at sea should not prevent the development of new technologies for the disposal or reuse of wastes on land. There was agreement that as far as the current state of knowledge was concerned, the present methods of incineration at sea should be regarded only as a temporary solution to the problem.

In general, incineration at sea should be strictly regulated and only those wastes which can be completely destroyed should be incinerated under these circumstances. All ocean combustion operations should be carefully monitored to ensure that they are being carried out in an environmentally acceptable manner.

8. Research and development

Research and development are a necessary first step in problem solving which involves defining the problem, measuring its impact and searching for solutions.

The previous chapters of this report have documented the results of research and development, leading to the implementation of new and improved technologies and systems for the thermal treatment of hazardous wastes.

Although it has been proved that incineration for certain harmful materials is the most highly developed disposal technique, there remains a considerable number of problems to be solved. Potential environmental impacts are not completely known although it is generally recognized that these may be lessened through pollution control devices such as scrubber units. The residual ash may be toxic and must be properly disposed of. In addition, the data base for incineration of special new wastes, such as pesticides which have not been treated by this means so far needs to be expanded. Different types of incinerators (multiple hearth, rotary kiln, fluidized bed, liquid injection) are versatile units capable of incinerating a wide variety of solid, liquid and gaseous combustible wastes. Nevertheless, it is necessary to determine the appropriate emission control systems and the conditions of operation to be used and to take into account residence time, turbulence, temperature and combustion air in order to efficiently incinerate hazardous wastes. Co-incineration is another field of investigation of particular interest. Other items of research and development is pyrolysis mainly to reclaim raw materials and energy.

The emphasis in research and development differs from country to country. This depends on whether

- incineration is already a well-developed and widespread technology for treating hazardous wastes,
- incineration is considered as to be a viable technology for these types of wastes in the future,
- there are severe problems with the disposal of certain types of waste which require this type of solution.

In the United States of America much research has been carried out on the laboratory scale for the incineration of organic pesticides. The main conclusion is that in well-designed systems which are properly maintained and operated organic pesticides may be $\geq$ 99,99% destroyed at 1.000° C with a two-second retention time and adequate excess air. The results of these tests have also shown that emission control devices are necessary for pesticide incineration. Emissions potentially requiring control include particulates from solid formulations, P_2O_5 from phosphorus-based pesticides, HCl from chlorinated hydrocarbons, CN^- from nitrogen containing organics and SO_2 from organo-sulfur compounds. Odour was also a problem, particularly during the incineration of organo-sulfur pesticides. But because the data base for pesticide incineration has been developed largely with experimental incinerators, extrapolation of the findings to full-scale conditions is limited. More pilot-scale demonstrations should be conducted utilizing commercial units so that the results may be directly applicable to solving field disposal problems. Furthermore, the data-base for pesticide incineration should be expanded to include more representative classes of pesticides. Finally, potential environmental and economic cost impacts have not yet been completely defined.

Additional items of laboratory research and development in the U. S. were:

- evaluation of high temperature destruction of PCBs and related compounds
- development of microwave plasma detoxification process of hazardous waste (e. g. detoxification of Navy Red Dye).
- thermal destruction analytic system

At the pilot-scale level the following work is being carried out:

a) development of pilot-scale microwave plasma detoxification process for hazardous wastes (quartz tube reactor chamber mainly for pesticides in an oxygen carrier gas with microwaves) (Lockheed Research Center, Palo Alto, California)

b) incineration of hazardous wastes in beds of molten sodium carbonate (Rockwell International, Canoga Park , California)

c) design and development of a mobile hazardous waste incinerator (U.S. EPA) and

d) parametric evaluations prior to field-scale incineration for numerous hazardous wastes (U.S. EPA, Pine Bluff, Arkansas).

An advantage of item a) is the reduced temperature of combustion (the gas itself has a temperature of only about 540° C) which would make it easier to control emissions and corrosions. The wastes are mixed with oxygen and passed into the reactor where they are ionized into a plasma. The net result is that the waste is completely consumed but with less expenditure of energy than is required for conventional incineration. Much more work will be needed, however, before the cost of the process is reduced to that of conventional incineration.

In the process named under item b) waste and air are continually introduced under the surface of the melt which is kept at a temperature of 800 to 1000° C and are combusted instantaneously and completely. By-products such as hydrogen chloride and sulphur dioxide are instantly absorbed and neutralized by the alkaline sodium carbonate. The process is still in the experimental stage, however, and is likely to be uneconomic unless major improvements can be achieved.

The objectives of item d) clearly indicate those areas in which further investigations are still needed after laboratory evaluation is completed. The objectives of this research project are reproduced as an example: the project shall conduct parametric investigations on a thermal disposal technology for a variety of hazardous wastes. Data will be developed for incinerator design capabilities, efficiency of various air pollution control devices, materials handling problems and suggested alternative disposal solutions to difficult waste streams such as organo-metallic compounds. End use of the data generated for this research effort will be to supply design and implementation information to those programs charged with licensing disposal operations in order to accept or reject certain wastes. By establishing lower limits on operating conditions for incineration technology, certain design considerations will be incorporated that will minimize energy requirements and other problems. The lower limits will also permit controlling agencies to establish operating conditions from a supporting data base rather than requiring extremely severe conditions due to an insufficient data base.

In the Netherlands investigations in the past have concentrated on incineration of hazardous wastes at sea. The occurence of organic chlorides in the combustion products of an EDC tar burned on the incineration vessel Vulcanus was investigated. Further investigations of the incineration of hazardous wastes on another vessel, the Matthias II was carried out in 1978. At present almost no R and D is being carried out on a greater than laboratory scale. Investigations are in progress on fluidized bed incineration, and it is hoped that for certain types of chemical wastes research can be carried out in this apparatus.

Although little research work is grant-aided at present from the government in Norway it is intended to sponsor a current project on incineration in a cement kiln combined with pyrolysis of solid hazardous and municipal wastes.

In Great Britain the Warren Spring Laboratory (of the Department of Industry) has worked in the past on pyrolysis of domestic waste which is government funded, and work on the pyrolysis of tyres has been carried out on a customer/contractor basis for a private company.

The Waste Research Unit of the Hazardous Materials Service, Harwell is carryingout laboratory-scale work for the Department of the Environment on the thermal treatment of hazardous wastes as follows:

- pyrolysis of polychlorinated biphenyls (PCBs), ethylene dichloride tars and tyre materials in molten salt reactors
- a tube furnace has been constructed in the laboratory to examine the incineration parameters of pesticides and related wastes.

The aim of the work is to update guidance given in the Department's codes of practice for the disposal of various hazardous wastes.

The Department has commissioned bench-scale exploratory work on the reaction of PCBs in molten beds of chemically reactive materials, the aim being to dechlorinate and thus detoxify PCB at relatively low temperatures.

Promising results have been obtained with an eutetic mixture of sodium and potassium hydroxides. Investigations are now taking place with molten sodium as the reactive medium and indications are that, in addition to detoxifying PCB wastes, an aromatic feedstock and/or a mixed hydrocarbon fuel may be recovered.

In France since 1979 certain industrial wastes have been incinerated in cement kilns on an experimental basis. Early results gained so far are encouraging indicating a fixation of toxic substances in the clinker (heavy metals, chlorine etc.).

Attention is also being focussed on controlling and monitoring various incineration plants. The results of these observations will enable problems arising from stack emissions and the dispersion of incineration residues to be better controlled.

In the Federal Republic of Germany the following items of research are being carried out:

1. Incineration at sea: extensive investigations have been carried out on board of the new incineration vessel "Vesta" to obtain data on combustion efficiency, emissions and the impact of incineration on the sea as a basis for further approvals for this kind of disposal.
2. Incineration on land: grants will be given for the construction of a new supra-regional hazardous waste incinerator which will be equipped with a new emission control device which is a scrubbing system with in-line drying reactor.
3. Safe and final disposal of certain chemical warfare residues of World War II (and earlier) as gas granades containing "Gelbkreuz, Senfgas, Lost" begin to corrode with loss of contents. A specially designed incinerator is under construction and is due to go into operation in 1980. The whole facility (including pretreatment and aftertreatment) worth approximately 10 M DM (including appr. 6 M DM for the incinerator) will have a capacity of about 25 kg/h or 44 t/a.

4. With regard to new thermal treatment techniques, the following three pilot facilities are of interest:

   - the SFW process which combines the gasification of domestic and industrial wastes in a shaft furnace with a considerable degree of gas purification and separation (pilot plant 1 t/h).
   - the pyrolytic recovery of raw materials in an indirectly heated rotary kiln, from waste cables, waste tyres, rubber, plastics, acid tars and similar wastes (MVU-Process, 200 kg/h pilot plant)
   - the high temperature combustion of wastes (Andco-Torrax-System) such as househould waste, hospital waste, fly ash from electrostatic precipitators from household incinerators, waste tyres and similar wastes (demonstration unit 8 t/h, Frankfurt).

9. Condusions and Recommendations

Conclusions

1. The promulgation of air and water pollution control regulations has resulted in more effective removal of contaminants from waste streams, especially the hazardous constituents in many industrial effluent streams. These clean-up activities have resulted in an increased quantity of concentrated hazardous wastes that must be disposed of. Growing concern of the possible deterioration of the environment from current disposal methods has led governments to seek more acceptable ways for industry to dispose of its hazardous wastes.

2. Many disposal techniques have been utilized or proposed, none of which is problem free. Problem areas encountered include adverse environmental impacts, exessively high costs and scarcity of acceptable sites.

3. As the quantity of these wastes increases, the need for advanced waste management technologies becomes increasingly important. Even if carried out under strict control, landfill disposal is not effective for final deposition of certain types of hazardous wastes. In this respect, incineration as an integral part of the whole disposal concept is likely to be a more desirable environmental option for final disposal of many organic hazardous wastes, provided stringent controls are executed.

...

4. Recent trends in certain countries appear to indicate that the increase in hazardous waste generation has resulted in a corresponding increase in the construction of hazardous waste incineration facilities, and is likely to play an increasingly important role in the disposal of hazardous wastes.

5. The continued increase in oil prices is likely to result in a decrease in the availability of combustible wastes. Therefore, a prime factor in deciding on the construction of a new incinerator is to properly estimate the composition and amount of waste likely to be available in the future.

6. Experience shows that large capacity plants (depending on the calorific value and the amount of waste available) are preferable because of

   - economy of scale
   - the possible application of the best technology available
   - a better environmental control and
   - a greater variety of energy use (e.g. for emulsion separation, for evaporation of aqueous wastes or for thickening sludges prior to incineration).

7. Where there are insufficient satisfactory treatment and/or disposal options on land, incineration at sea is a viable disposal option under stricty controlled conditions, as a temporary solution.

8. Several thermal processes (e.g. pyrolysis) are being investigated which has led to the construction and operation of a few large-scale demonstration plants. Further investigations will consider fault liability, availability, optimization of the plant throughput, utilization of the energy and raw materials obtained, treatment of the pollutants generated and, in particular, more precise determination of the operating costs. Specific results from these follow-up studies are not likely to be obtained in less than two years.

...

9. High costs have, in the past, limited the use of incineration but increasing costs and the potential liabilities associated with other techniques are making controlled combustion much more attractive. Since incineration is an expensive disposal option, it is hoped that other developments may be promoted to handle such wastes, in particular recycling. Alternatively, the primary interest of reducing the amount of waste at the producer end and the utilization of wastes as sources for energy or secondary raw material may be more rapidly approached.

10. Thermal treatment of hazardous wastes is basically (besides volume reduction) a method for the destruction of harmful substances in a short and controlled space of time with no cost associated with further monitoring and no future liability. For certain types of special wastes it is the most appropriate disposal method and should be applied irrespective of the short-term cost with respect to avoid still higher costs which may otherwise subsequently arise particulary from landfills after closure.

Recommendations

1. There is still little information available on
   - siting of thermal treatment plants
   - plant technology
   - waste types suitable for thermal treatment.

   Future investigation should therefore be focussed on these questions in order to obtain a more realistic basis from which a more widespread application of incineration can be derived.

2. Unless incineration is carried out under strict control, this disposal method basically replaces soil/water pollution resulting in the case of landfilling by an

...

unacceptable contamination of the atmosphere (e.g. dust and noxious gases). Thus research is needed:

- to determine operating conditions and emission limits in relation to environmental impact
- to develop and harmonize international regulations [1]
- to intensify the development of gas cleaning devices (filters, wet scrubbers, dry adsorption systems) for removing noxious gases as well as fine particles ($<$ 0,1 microns) and aerosols from the flue gas and
- to better define by-products of combustion.

3. Incineration is expensive even with energy recovery systems, although energy recovery both reduces the costs of incineration and saves fuel. At a time of rising energy prices the equipment of new incinerators with heat recovery devices should be considered in order to reduce the cost of incineration and/or to save fuel.

4. Co-incineration of hazardous wastes and municipal wastes can be applied if performed in a safe and environmentally acceptable manner. The potential for co-incineration warrants further investigation. Specifically the types and quantities of hazardous wastes in relation to the types and quantities of municipal waste needs to be determined.

5. When incinerating hazardous wastes they should be used as a fuel substitute as far as opssible. The waste - as - fuel concept should be further investigated, particulary the use of hazardous wastes as a fuel supplement in cement kilns and power stations.

6. Prior to incineration, the development and application of new recovery techniques should be promoted such as HCl recovery from high chlorinated organic wastes.

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[1] Although it is suggested that any regulations should be similar for all nations, a major debate still continues on "emission standards" versus "environmental quality objectives" for effluent discharges, depending upon the philosophical approach of the particular country.

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7. Whereas large companies often operate their own on-site waste disposal facilities, waste disposal options or plans need to be developed mainly for small to medium size waste generators. There should be cooperation therefore in the provision of centralized plants, if necessary, linked via transfer stations which could include certain pretreatment methods. Such disposal facilities could be constructed and operated by public or private funding or by a combination of both.

8. The pollution of incinerator residues (bottom ash, fly ash and scrubber sludge) needs to be determined more thoroughly since little information is currently available. In particular, residue characteristics in relation to input composition and incineration conditions, long term residue leaching, fly ash characterization and separation techniques require further research and development.

9. Evaluation procedures concerning environmental impacts and efficiency of incineration should be further developed. Efforts in this regard should aim at the elaboration of standardized incineration tests for use as a management tool.

10. On-site hazardous waste incineration should be subject to the same regulations as for off-site hazardous waste incineration.

11. The development of new thermal treatment processes for hazardous wastes, e.g. pyrolysis should be regarded as supplement to the range of conventional methods of waste disposal and may offer more flexible options for the treatment of waste.

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References

1) Ahling, B. and Johansson, L.: Combustion Experiments using Pentachlorophenol on a Pilot Scale and Full-Scale in Chemosphere Nr. 7 1977 page 425-436

2) Ahling, B.; Lindskog, A.; Jansson, B.; Sundström, G.: Formation of Polychlorinated Dibenzo-p-dioxins and Dibenzo-furans during combustion of a 2,4,5-T Formulation in Chemosphere No. 8 1977, page 461-468

3) Buser, H.R.; Bosshardt, H.-P.; Rappe, Ch.: Identification of Polychlorinated Dibenzo-p-Dioxin isomers found in fly ash in Chemosphere No. 2 1978, page 165-172

4) Dartoy, J., Simon, D.: Etude des charactéristiques et des domaines d'emploi des incinérateurs de déchets industriels, Report to the French Ministry of the Environment, Battelle-Geneva, April 1976

5) Dartoy, J.: The incineration of hazardous waste, Process-Engineering Group 191-4605/JD/dm, Battelle-Geneva, December 1979

6) Fabian, H. W., Reher, P., Schoen, N.: How Bayer incinerates wastes, Hydrocarbon Processing, April 1979, pp. 183 - 192

7) Fäßler, Leib, Spähn: Korrosionen an Müllverbrennungskesseln, Mitteilungen der VGB, Heft 2 1968, pp. 126 - 139

8) Gromotka, H.: Industrieabfall- und Sondermüllverbrennung in: U - das technische Umweltmagazin, März 1978

9) Incineration at Sea

- Incinération en haute mer de résidus industriels chlorés, 1974 Report by the Minisère de la qualité de la vie, France
- On the occurrence of organic chlorides in the combustion products of an ECD-tar burnt by the incineration ship Vulkanus, a preliminary investigation, 1974. Report by H. Compaan, TNO Central Laboratory, no. C 1 74)93), commissioned by the North Sea Directorate of the Department of Public Works, Rijswijk, the Netherlands.
- Disposal of organochlorine wastes by incineration at sea, 1975. Report EPA - 430/9 - 75 - 014, July 1975. U.S. Environmental Protection Agency.
- At sea incineration of organochlorine wastes on board the M/T Vulkanus. Report EPA 600/2 - 77 - 196, September 1977. U.S. Environmental Protection Agency.
- At sea incineration of herbicide orange on board the M/T Vulkanus (1978). Report EPA 600/2 - 78 - 086, April 1978. U.S. Environmental Protection Agency.
- At sea incineration: sampling analysis and environmental assessment. Draft final report, February 1979 (31497 - 6022 - RU - 00). TRW, Triangle Park, North Carolina.

10) Kearney, P.C.; Woolson, E.A.; Isensee, A.R.; Helling, C.S.: Tetrachlorodibenzodioxin in the Environment: Sources, Fate, and Decontamination in Environmental Health Perspectives, September 1973, page 273-177

11) Langer, H.G.; Brady, T.P.; Briggs, P.R.: Formation of Dibenzodioxins and other Condensation Products from Chlorinated Phenols and Derivatives in Environmental Health Perspectives, September 1973, page 3-7

12) Olie, K., Vermeulen, P.L., Hutzinger, O.: Chlorodibenzo-p-dioxins and Chlorodibenzofurans are trace components of fly ash and flue gas of some municipal incinerators in the Netherlands, Chemosphere No. 8, pp. 456 - 459, 1977

13) Reimer, H.: Kontinuierliche und diskontinuierliche Verbrennung von Sonderabfällen in: Sonderabfallbeseitigung, edited by Thomé-Kozmiensky, Erich Schmidt Verlag, Bielefeld 1977

14) Wilson. David C.: Recent developments in the management of hazardous wastes, Atomic Energy Authority, Harwell, Oxfordshire, Great Britain, September 1978

Appendices

Appendix I	General questionnaire
Appendix II	Special questionnaire
Appendix III	Costs of incineration
Appendix IV	How Bayer incinerates wastes
Appendix V	Commercially available hazardous waste incinerators in the United States
Appendix VI	Hazardous waste incinerators in the Federal Republic of Germany

Attachment 1

GENERAL QUESTIONNAIRE

(to be answered by the expert authorities of the participating countries - please print)

1. The following wastes can be treated thermally (i. e. by drying, evaporation, degassification, gassification or pyrolysis, incineration). -

   Please give estimates of the quantities of the relevant wastes generated in your country and the fraction thereof treated thermally (in metric tonnes per year).*

No.	Type or Group of Wastes	Total Amount (t/a)	Amount Treated Thermally (t/a)
1	waste mineral oils		
2	drilling and grinding emulsions		
3	oil emulsions and oil mixtures		
4	mineral oil sludges		
5	refinery wastes containing mineral oil, incl. acid tar and spent clay		
6	grease and wax wastes		
7	glue, putty and not congealed resin wastes		
8	varnish and paint wastes and sludges		
9	plastics, rubber and latex wastes		
10	plastics, rubber and latex sludges and emulsions		

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*) You may combine certain wastes into groups and give estimates for the groups, or you may break down groups of wastes and specify or add waste types at the end of this list.

No.	Type or Group of Wastes	Total Amount (t/a)	Amount Treated Thermally (t/a)
11	phenolic wastes		
12	solvent wastes and sludges		
13	pesticide wastes		
14	organic wastes containing halogen, sulphur or phosphorous compounds		
15	cellulose production and processing wastes		
16	tannery wastes		
17	odourous food and spice processing wastes		
18	pickling liquors from metal finishing		
19	acids (possibly specified by sources and composition)		
20	alkalies (possibly specified)		
21	industrial effluents (possibly specified)		
22	industrial effluent treatment sludges		
23	water treatment sludges		
24	sewage treatment sludges		
25	explosives, ammunitions, warfare chemicals		
26	others (please list consecutively)		

2a. How many incinerator plants in your country are operated exclusively for hazardous or special wastes? ....

b. How many of the above plants are owned and operated

- publicly ....
- privately ....
- joint ventures ....

c. How many of these plants are mobile (e.g. incineration at sea) ....

d. What is the estimated overall capacity of these plants (in tonnes per year)? .... t/a

3a. How many incinerator plants in your country accept hazardous or special wastes in addition to residential and commercial wastes? ....

b. Generally, what types of wastes are these? - Please pick numbers from the listing page 1 and 2:

....

....

c. In what proportion by weight are these hazardous or special wastes generally added? ....

d. Are the incinerator plants according to 3a obliged by their statutes to accept hazardous or special wastes or is it a voluntary service, limited temporarily or by other criteria? - Specify:

....

....

....

....

4. Are there in your country industrial plants where hazardous or special wastes serve, on an operational basis, as substitute fuel (e.g. in cement manufacturing)?

No. of plants	Industrial Branch	Types of waste	Amounts (t/a)

5. Besides incineration, are hazardous or special wastes also subjected to other kinds of thermal treatment, e.g. degassification or pyrolysis?

No. of plants	Kind of Treatment	Types of Waste	Capacity (t/a)

6. How do you judge thermal treatments (drying, evaporation, incineration, degassification, pyrolysis etc.) of hazardous and special wastes with regard to

a) volume reduction

....

....

....

....

b) energy use

....

....

....

....

c) raw material recovery

....

....

....

....

d) rendering harmless the wastes, so that residues can be disposed of without special precautions

....

....

7. Which R&D projects are financially sponsored in your country by the government with regard to thermal treatment of hazardous or special wastes? -
Brief description of aims, processes, and status of the work:

....

....

....

....

....

....

....

....

8. What sort of organizational conditions exist in your country for the operation of thermal treatment plants for hazardous and special wastes (e.g. laws, regulations, guidelines, standards, instruction sheets).*

....

....

....

....

....

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*) relating to questions 4 through 8 please attach literature citations, reprints, specimens of pertinent legislation etc.

Attachment 2

QUESTIONNAIRE ON THERMAL TREATMENT PLANTS FOR HAZARDOUS WASTES

(to be forwarded to and answered by the operator of a respective installation - please print or type)

1. Installation

1.1 Description of installation:

....

....

....

....

1.2 Address (or Stamp):

1.3 The plant is owned and operated (please check):

☐ public ☐ private ☐ joint venture

1.4 Date or year operation started: ....

1.5 Reference date for all data following in this report: ....

1.6 Number of population served by this installation: ....

1.7 Area of collecting region of the installation:

☐ .... square miles or ☐ .... km^2

1.8 How many collection and transfer stations are linked to this installation and where are they located ?

Number: .....

Places: ....

....

....

....

2. Delivery of wastes

2.1 Delivery (in percentage).

☐ by public collection and transport enterprises ...... %

☐ by private collection and transport enterprises ...... %

☐ directly by waste generator: ...... %

☐ other (please specify): ...... %

....

....

....

....

2.2 Predominant way of delivery (please check):

☐ in tank lorry

☐ by truck

☐ by ship or barge

☐ by train

☐ via pipe-line

☐ in drums or other small containers (specify):

....

....

....

Capacity of containers:

☐ .... kilograms or ☐ .... litres or ☐ .... gallons

☐ one way containers

☐ refillable containers

3. Throughput of the entire plant

(in metric tonnes or cubic metres per year - if different units are used, please indicate)

3.1 Throughput (please check)

t/a	m^3/a

☐ in continuous operation

☐ in discontinuous operation

3.2 Possible maximum capacity according to manufacturer's data:

t/a	m^3/a

3.3 Foreseeable alteration of plant capacity

(increase: +, decrease: -)

Date set: ....

t/a	m^3/a

4. Operation and personnel

4.1 Number of working days per week: ....

4.2 Average number of hours of operation per year: ....

4.3 Number of permanently employed, incl. maintenance and laboratory personnel: ....

4.4 Citizen acceptance of the installation:

a) objections during planning or construction ☐ yes ☐ no

b) objections during operation (please comment):

....

....

....

....

5. Determination of waste properties

5.1 Determination of weight (please check):

- ☐ by regular weighing
- ☐ by occasional weighing
- ☐ estimates only
- ☐ no determination of weight

5.2 Determination of volume of wastes:

- ☐ by estimates of the carrier volumes
- ☐ by estimates of container volumes

☐ by measurement upon delivery

☐ no determination of volume

☐ other means of determination (please specify):

....

....

5.3 Identification of waste (please check):

☐ by sample analysis prior to delivery

☐ by visual inspection upon delivery

☐ by sampling and analysis upon delivery

☐ by analysis at regular intervals

☐ by analysis in cases of doubt

☐ no identification (please comment):

....

....

....

....

5.4 Parameters being determined and how*:

a) Physical Properties	Method Employed
☐ calorific value	....

---

*) if available please attach analytical procedures and data report sheets

a) Physical Properties Method Employed

☐ water content ....

☐ suspended solids content ....

☐ ash content ....

☐ specific density ....

☐ vapor pressure ....

☐ evaporation number ....

☐ ignition temperature ....

☐ flash point

☐ explosion limits; range of ignition ....

☐ boiling point curve (e.g. analysis by fractional destillation) ....

☐ others (please specify):

....

....

....

b) Chemical Composition Method Employed

☐ pH ....

☐ organic compounds (major groups) ....

☐ halogenated organics (incl. PCB and chlorosilane) ....

b) Chemical Composition **Method Employed**

☐ organic silica compounds ....

☐ mercury (Hg) ....

☐ cadmium (Cd) ....

☐ lead (Pb) ....

☐ arsenic (As) ....

☐ copper (Cu) ....

☐ zinc (Zn) ....

☐ beryllium (Be) ....

☐ chromium (Cr) ....

☐ nickel (Ni) ....

☐ vanadium (V) ....

☐ iron (Fe) ....

☐ others (please specify):

....

....

....

....

c) Biological Parameters — Method Employed

☐ toxicity ....

☐ biodegradability ....

☐ accumulation or metabolization in organisms ....

☐ others (please specify):

....

....

....

....

5. Wastes delivered to this installation
(please check):

① waste mineral oils
② drilling and grinding emulsions
③ oil emulsions and oil mixtures
④ mineral oil sludges
⑤ refinery wastes containing mineral oil, incl. acid tar and spent clay
⑥ grease and wax wastes
⑦ glue, putty and not congealed resin wastes
⑧ varnish and paint wastes and sludges
⑨ plastics, rubber and latex wastes
⑩ plastics, rubber and latex sludges and emulsions
⑪ phenolic wastes
⑫ solvent wastes and sludges

⑬ pesticide wastes

⑭ organic wastes containing halogen, sulphur or phosphorous compounds

⑮ cellulose production and processing wastes

⑯ tannery wastes

⑰ odourous food and spice processing wastes

⑱ pickling liquors from metal finishing

⑲ acids (possibly specified by sources and composition)

⑳ alkalies (possibly specified)

㉑ industrial effluents (possibly specified)

㉒ industrial effluent treatment sludges

㉓ water treatment sludges

㉕ explosives, ammunitions, warfare chemicals

㉖ others (please list consecutively)

....

....

....

....

7. Wastes explicitly excluded by the statutes of this facility (please specify):

....

....

....

....

....

8. Pretreatment and any follow-up-treatment of wastes

With regard to specific types of wastes please give examples of typical treatments applied prior to or after the actual thermal treatment.

Such treatments could, for instance, be:

a) milling, pulverization
b) detoxification
c) neutralization
d) decanting
e) dewatering, dessication
f) filtration
g) emulsion separation
h) destillation, fractionation
i) homogenisation
k) consolidation, cementation
l) liquification by heating (please specify temperature in centigrades)

Please indicate in column 2
the consistency of the wastes prior to pretreatment:

S: solid
P: semisolid, pasty, tarry
L: liquid

Please indicate in column 4, where the treatment does take place:

A: pretreatment at source,
B: pretreatment at transfer station,
C: pretreatment at this installation,
Z: follow-up treatment at this installation or elsewhere.

1 Type of Waste	2 Cons.	3 Kind of Treatment	4 Where	Amount (t/a)	Fees per Unit

9. Thermal treatment process(es)

Note: if different systems are installed at your facility, please answer the questions under 9 separately for each system

9.1 Type of reaction chamber (please check):

☐ open reactor (reaction at atmospheric pressure)

☐ closed reactor, operated at a pressure of .... bars

☐ continuous waste throughput

☐ discontinuous waste throughput

9.2 Reactor system (please check):

☐ shaft furnace, cupola furnace

☐ fluidized bed reactor

☐ rotary kiln

☐ grate

☐ muffel furnace

☐ firebox furnace, flame chamber furnace

☐ electric furnace

☐ other (please specify):

....

....

....

9.3 Heating of reactor:

☐ direct (internal) heating by combustion of wastes; excess-air coefficient λ=.......

☐ direct heating by partial combustion of wastes

☐ direct heating by superheated steam and/or hot gases

☐ indirect (external) heating by gas or oil burner

☐ other (please specify):

....

....

....

9.4 After burner chamber: ☐ yes ☐ no

9.5 Heating of after burner:

☐ direct (internal) heating by combustion of the flue gasses with

  ☐ addition of secondary air; excess-air coefficient λ = ...

  ☐ addition of liquid wastes

☐ direct heating by partial combustion (cracking) of the flue gasses with addition of secondary air ($\lambda < 1$)

☐ indirect (external) heating by gas or oil burner

☐ other (please specify):

....

....

....

9.6 Use of additonal primary fuel (not waste fuels)

a) in the reactor:

☐ continuously

☐ as required

☐ oil; consumption per metric tonne of waste: ..../t waste

☐ gas; consumption per metric tonne of waste: ..../t waste

☐ other (please specify):

....

....

....

....

b) in the after burner:

☐ continuously

☐ as required

☐ oil; consumption
per normal cubic meter of flue gas: ...../Nm^3 gas

☐ gas; consumption
per normal cubic meter of flue gas: ...../Nm^3 gas

☐ other (please specify):

....

....

....

9.7 Casing (lining) material

a) of the reactor chamber: ....

b) of the after burner chamber: ....

9.8 Process temperature (in degrees Kelvin)

a) in the reactor ....° K

b) in the after burner ....° K

9.9 Average residence time

a) of waste in reactor: .... minutes

b) of crude gas or flue gas in the after burner: .... seconds

9.10 How many reactors of this type are installed at your facility?

☐ in operation ....

☐ in reserve .... Total: ....
========

9.11 Theoretical capacity per unit in continuous operation (given in metric tonnes of waste per hour): .... t/h

9.12 Maximum admissible thermal load during continuous operation (given in gigajoules per hour): .... GJ/h

9.13 Steam generator

a) steam pressure: .... bars

b) steam temperature: .... ^{o} K

c) capacity in metric tonnes of water per hour: .... t H_2O/h

d) boiler efficiency in per cent: .... %

10. Products and wastes from the installation

10.1 Destination of heat energy (please check):

☐ transfer to power plant

☐ transfer to heating plant

☐ transfer to industrial users

☐ on-site generation of electricity

☐ no energy utilization

☐ other use (please specify)

....

....

10.2 Bottom ash and slag:

a) quantity

- in metric tonnes per year: .... t/a
- in kilogrammes per tonne of waste treated: .... kg/t waste

b) disposal or utilization, with or without follow-up treatment (please comment):

....

....

....

10.3 Fly ash:

a) quantity

- in metric tonnes per year .... t/a
- in kilogrammes per tonne of waste treated .... kg/t waste

b) average chemical composition (please state units):

carbon (C) ....
sulphur (S) ....
chlorine (Cl) ....
water (H_2O_2) ....
alumina ($Al_2 O_2$) ....
silica (SiO) ....
heavy metal content ....

c) disposal or utilization, with or without follow-up treatment (please comment):

....

....

....

10.4 Other solid residues

from waste treatment (e.g. scrap, coke etc - please specify):

a) types
b) quantities
c) disposal or utilization

....

....

....

10.5 Effluent from gas washer

(scrubber)

a) quantity
- in litres per year .... l/a
- in litres per tonne of waste treated : .... l/t waste

b) average chemical composition:

evaporation residue ....
loss on ignition ....
pH ....
electric conductance ....
BOD_5 ....
COD ....
sulphate ....
chloride ....
calcium (Ca) ....
magnesium (Mg) ....
chromium (Cr) ....
arsenic (As) ....
lead (Pb) ....

other elements (please specify):

....

....

....

b) treatment and disposal of effluent
(please check):

☐ mechanical treatment

☐ biological treatment

☐ chemical treatment

☐ evaporation

☐ other kind of treatment (please specify):

....

....

☐ no effluent treatment

☐ discharge into ....

10.6 Other effluents or liquid residues
(e.g. pyrolysis oil - please specify):

a) types
b) quantities
c) treatment, disposal or utilization

....

....

....

....

10.7 Sludges

(e.g. from wet scrubber, effluent treatment etc. - please specify):

a) types
b) quantities
c) treatment, disposal or utilization

....

....

....

....

10.8 Gaseous products or residues other than flue gas (e.g. fuel gas from gassification processes - please specify):

a) types
b) quantities
c) treatment, disposal or utilization

....

....

....

....

11. Flue gas cleaning

11.1 By what means are fly ashes removed from the flue gas?

....

....

11.2 By what means are gaseous components (e.g. SO_2, HCl) removed from flue gas (e.g. wet scrubber, dry scrubber - give construction and name of manufacturer):

....

....

....

11.3 What is the remaining average concentration of harmful constituents in the exhaust gas (in milligrammes per normal cubic meter):

mg/Nm^3

chloride (Cl^-) ....

fluoride (F^-) ....

sulphur dioxide (SO_2) ....

nitrogen oxides (NO_x) ....

carbon monoxide (CO) ....

dust ....

other (please specify):

....

....

....

11.4 Average amount of exhaust gas during continuous operation (in normal cubic meters per hour):

.... Nm^3/h

11.5 What are the applicable emission limits according to law, technical guidelines or licensing conditions for your installation (please state units):

chloride (Cl^-) ....

fluoride (F^-) ....

sulphur dioxide (SO_2) ....

nitrogen oxides (NO_x) ....

carbon monoxide (CO) ....

dust ....

other (please specify):

....

....

....

....

11.6 What other conditions with regard to emissions, noise operational procedures, monitoring needs etc. apply to your installation (please specify):

....

....

....

....

12. Operating experience with this installation

12.1 Problems derived from chemical properties of wastes, and means to overcome these problems (e.g. corrosion problems; incomplete combustion; reactions of fly ash with surfaces; volatility or solubility of certain metal compounds, etc. - please specify):

....

....

....

....

12.2 Problems caused by physical condition of wastes, and means to overcome them (e.g. trouble to conveying devices; charging or discharging of reactor; pretreatment or follow-up treatment of wastes or residues, etc. - please specify):

....

....

....

....

12.3 Other technical problems and possible solutions (e.g. erosion of linings; boiler problems; slag problems, etc. - please specify):

....

....

13. Construction costs

(approximations or estimates)

Currency:

13.1 Purchase of construction site: ....

13.2 Cost of buildings: ....

13.3 Cost of operational facilities

- waste pretreatment and follow-up treatment facilities: ....
- reactor(s): ....
- scrubber(s): ....
- flue gas filter(s): ....

13.4 Cost of infrastructure: ....

13.5 Ancilliary costs of construction: ....

13.6 Subsidies to construction costs: ....

14. Running costs per year

(approximations or estimates)

14.1 Personnel costs (salaries, wages, social benefits etc.): ....

14.2 Material costs (fuel, electricity, water etc.): ....

14.3 Maintenance costs: ....

14.4 Capital service (interest, depreciation etc.) ....

14.5 Running cost for analyses of wastes and treatment residues as well as monitoring (e.g. of exhaust gases and effluent discharges): ....

14.6 Any other outgoings (taxes, insurance, leasing etc.): ....

....

....

15. Regular earnings per year
(approximations or estimates)

15.1 Income from charges: ....

15.2 Income from sales: ....

15.3 Regular subsidies: ....

16. Average treatment and disposal costs
(per metric tonne of waste): ..../t waste

Questionnaire processed by:

Name Institution/Place Date

IF AVAILABLE PLEASE ATTACH ANY LITERATURE ABOUT THE INSTALLATION OR PROCESS, FLOW-SCHEMES AND PHOTOGRAPHS, INFORMATION ON RESEARCH CARRIED OUT AT THIS INSTALLATION, ETC.

Annex III Individual disposal costs - examples

Canada

Current costs for incinerators are not available. However, in 1978 a 50 GJ/h incinerator complete with gas cleaning equipment was estimated at $ 3.200.000. This figure does not include land, auxiliary services or design costs.

Netherlands

Costs for incineration at the Afvalverwerking Rijnmond (AVR) are in 1980

liquids (solid content < 5 % chlorines < 4 %)	
- bulk > 5.000 kcal	115,- f/t
- bulk < 5.000 kcal	175,- f/t
- 200 l container	375,- f/t
sludges	
- flash point > 100° C	178,50 f/t
- flash point < 100° C, < 2.500 kcal	178,50 f/t
- flash point < 100° C, > 2.500 kcal	240,- f/t
packed solids, max. 60 kg in containers up to 58 cm in diameter and 75 cm long	375,- f/t
solid wastes delivery in bulk per container	
- burnable in the grate incinerator (co-incineration)	178,50 f/t
- burnable in the rotary kiln	375,- f/t

In 1980 there has been an average price increase of 50 % over 1979.

Germany

A Biebesheim, Hessische Abfallverbrennungsgesellschaft mbH

(Pricing of February, 1977)

1.	Oil-Water-Mixtures (with impurities up to 5 %)	78,--		98,-- DM/t
2.	Emulsions from metal working industry (1 - 5 % oil content)	78,--		126,-- DM/t
3.	Oil sludges (from oil tanks; heavy impurities)	149,--		196,-- DM/t
4.	Oily residues from barrels	196,--		256,-- DM/t

an extra charge for handling the barrels is required

up to 50 kg = 3,75 DM/barrel

up to 100 kg = 7,45 DM/barrel

up to 200 kg 17,85 DM/barrel (exceptionally)

5.	Materials as gasoline, used for cleaning and testing purposes	196,--	-	270,-- DM/t

All prices do not include tax and transportation costs.

B Gesellschaft zur Beseitigung von Sondermüll in Bayern mbH, GSB

(Pricing of April, 1978)

1.	Waste oil (impurities < 10 %)	free of charge
2.	Oily, burnable fluids, pumpable at 20° C	105,-- DM/t
3.	Organo-chemical fluids with up to 2 % chlorine or sulphur and organic acids	295,-- DM/t
4.	Wastes containing phenol and cresol	295,-- DM/t
5.	Emulsions, not able to be separated	295,-- DM/t
6.	Photographic waste water	295,-- DM/t
7.	Paint residues containing solvents but without chlorinated hydrocarbons	295,-- DM/t
8.	Impregnated solids (oil content $>$ 3 %), residues from oil and petrol separation, cotton wastes (rags?)	295,-- DM/t

9.	Plastics, containing solvents but without chlorinated hydrocarbons	295,-- DM/t
10.	Solid bituminuous materials, tars, resins, mineral oil grease	295,-- DM/t
11.	Alcoholic mixtures, solvents not to be regenerated	295,-- DM/t
12.	Shredder waste, burnable	on request
13.	Others	295,-- DM/t (!)
14.	Material which needs special treatment prior to incineration	on request

For deliveries from outside the Bavarian State an extra charge of 10 % has to be paid!

Extra charge for handling the containers

- up to 60 l	2,50 DM/h
- more than 60 l, not to be drained	5,-- DM/h
- from 60 l to 200 l, to be drained	14,-- DM/h
- over 200 l, to be drained	28,-- DM/h
- palettes, each	28,-- DM/h
- laboratory tests	95,-- DM/h

No glas containers are accepted due for security reasons! Costs do not include tax and transportation.

France

Costs of incineration for hazardous wastes are on average about 300 F/t but the treatment costs vary very much depending on

- the nature of the waste (liquid, pumpable, high or low calorific value...)
- the different kinds of conditioning: not containorized, containorized, on palettes, ...

Each treatment center (see page 19) possesses its own settlement with costs varying from one center to the other. The following general rates are given:

0 - 100 F/t	liquids with high calorific value and a flash point of more than 55° C
up to 300 F/t	... with low calorific value
up to 200 F/t	... with flash point below 55° C
up to 300 F/t	liquids with impurities
200 - 500 F/t	pasty wastes
300 - 500 F/t	solid wastes
up to 200 F/t	if the waste is of low calorific value
about 150 F/t	if the wastes are on palettes in containers
about 200 F/t	if these containers are delivered in a dissoluted fashion

In case of special wastes other factors may be taken into account.

Annex IV

A reprint from Fabian, H. W.; Reher, P.; Schön, M.: How "Bayer" incinerates wastes", Hydrocarbon Processing, April 1979, pp. 183 - 192.

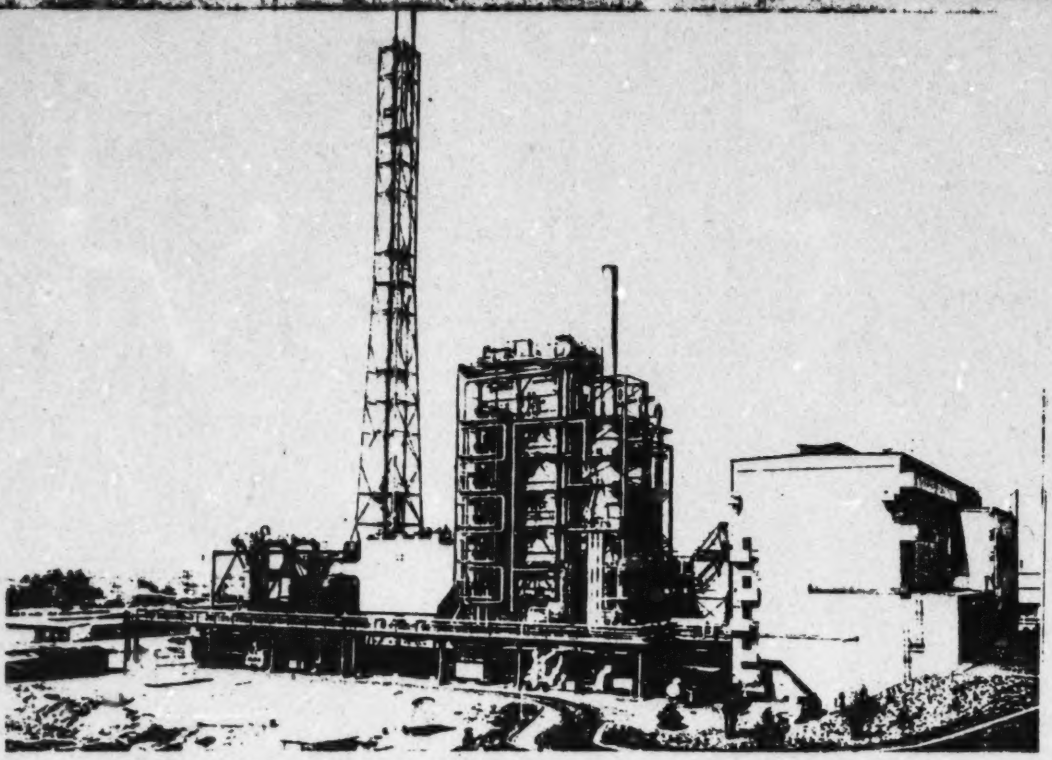

Fig. 1—Over-all view of the No. II incinerator system with flue-gas scrubber, seen from the west.

How Bayer incinerates wastes

This large chemical waste disposal system handles 25,000 tons per year of special wastes and produces 140,000 tons of steam while meeting current environmental rules

H. W. Fabian, P. Reher and **M. Schoen,** Bayer AG. Leverkusen, Germany

AFTER APPROXIMATELY one year of trials the No. II incinerator system at Bayer's Leverkusen plant was commissioned for regular service in November 1977. The construction of this system with downstream flue-gas scrubber had become necessary as a result of the increasing volume of waste and the additional requirements imposed for the disposal of "special waste."

The system's capacity allows the incineration of approximately 25,000 metric tons of special wastes per annum and produces approximately 140,000 tons of steam. It consists primarily of the waste bunker building, the rotary kiln with secondary combustion chamber including all feed devices for solid, paste and liquid waste, the heat recovery boiler, the electrostatic filter and the flue-gas scrubber which in turn consists of the injection cooler, two rotary scrubbers and one jet scrubber.

The purified flue-gas is heated in two heat exchangers and discharged by a suction blower via a stack of 100 m heighth. The stack is fitted with sensors and apparatus for the continuous measurement and recording of the type and quantity of the emissions. The scrubbing water is transferred to the company's own waste water treatment plant. Solid ash and dust are deposited in licensed disposal sites.

The system requires an operator staff of 35 persons including the instrumentation and maintenance personnel. The acquisition cost was DM 27 million. The system concept was developed in collaboration with L.&C. Steinmueller, D-5270 Gummersbach. Steinmueller was also the design and construction contractor. The operating cost is, DM 10 million per annum. The average incineration cost is DM 400 per ton of waste.

Background. In 1973 the construction of a second incineration system with downstream flue-gas scrubber was decided as a result of the increasing volume of "special waste" generated by the plants of Bayer AG.

It was planned to use this system for the disposal of all "special waste" as defined in § 2.2 of the Waste Disposal Act (Abfallbeseitigungsgesetz) dated June 7, 1972, and in accordance with the Federal Anti-Pollution Act (Bundesimmissionsschutzgesetz—BImSchG) dated March 15, 1974, and the Technical Directive on the Prevention of

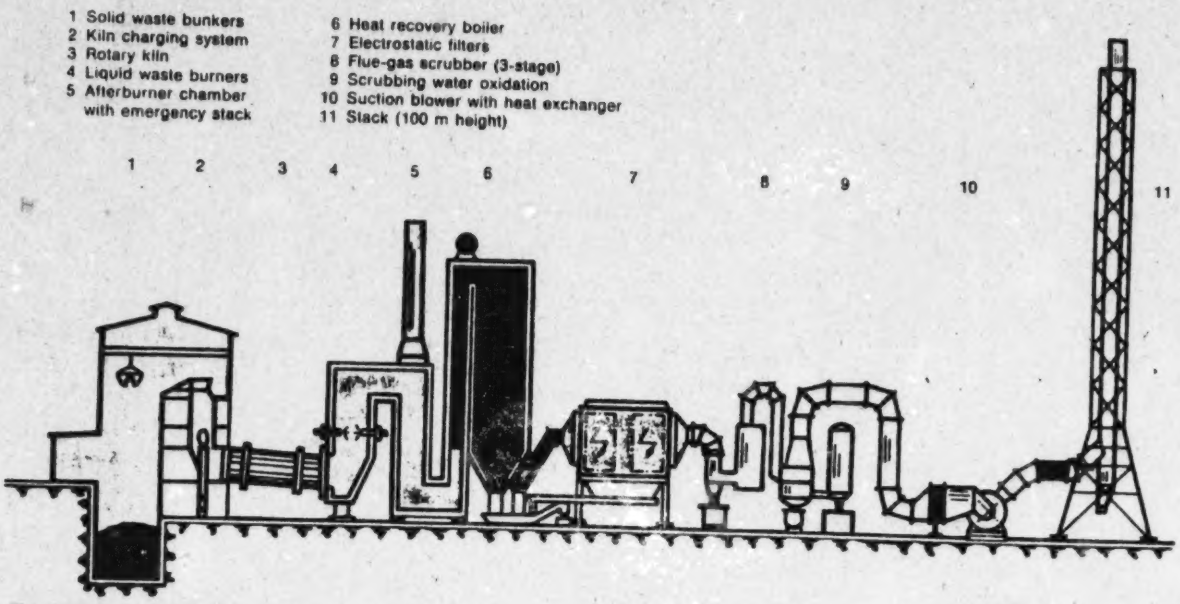

Fig. 2—Process schematic of the No. II incinerator system.

Air Pollution (Technische Anleitung zur Reinhaltung der Luft—TA—Luft) dated Aug. 28, 1974.

The following requirements were imposed on the design and operation of this system and the clean incineration of the "special waste" involved in accordance with the statutes:

1. Incineration must always be preceded by careful analysis and classification of the waste in order to determine the best suited treatment method.
2. The design, process technology and mode of operation of the incinerator system must be suitable for adaptation to the specific waste problems encountered, i.e., the system must be designed so that any change in the quantity and composition of the waste will not cause any malfunction in the process.
3. The design of the combustion spaces and heat recovery systems as well as the materials used for them must minimize the flue gas damage.
4. Finally, the flue-gas scrubbers must be designed so that removal of the pollutants from the flue gas is ensured regardless of quantity and ratio between the individual flue gas components.

SPECIAL WASTE

In order to facilitate special waste handling and to allow a certain classification which is also required for intermediate storage, this waste type was roughly classified into four categories on the basis of the chemical properties:

1. Halogen, nitrogen, sulfur, phosphorous and silicon-containing production waste,
2. Toxic, spontaneously igniting, spontaneously decomposing and spontaneously polymerizing waste as well as waste generating strong odors,
3. Waste of high reactivity which may react spontaneously with other waste or have a strong corrosive effect, and
4. Miscellaneous waste consisting of minor quantities of highly different waste whose composition is mostly unknown.

Classification under physical aspects would have been possible on the basis of the state of aggregation (solid, liquid) or on the basis of their calorific value which varies from 0 to 40,000 kJ/kg. However, in practical operations such a classification would not have been feasible since the chemical properties dominate.

INCINERATION PROBLEMS

In addition, the concept for the No. II incinerator system had been influenced by some basic considerations arising from the specific incineration problems of some waste types. As an example for these problems, the disposal of chlorine-, phosphorous- and silicon-containing waste and the heavy-metal-containing ash generated upon incineration shall be explained in more detail.[3]

Incineration of chlorine-containing waste. In addition to CO_2 and H_2O the incineration of chlorine-containing waste primarily produces HCl. The concentration of the generated HCl can be estimated fairly rapidly if the chlorine content of the waste and the excess air number are known. Thus it can be shown that the limit of 100 mg/nm^3 HCl in the exhaust air, which the German air pollution directive requires, will be reached and exceeded even when the waste has a very low chlorine content. For instance, the flue gases of waste containing

0.2% by weight chlorine, incinerated with 50% excess air, i.e., at $\lambda = 1.5$, already contains 160 mg HCl/nm^3. For waste whose chlorine content may be 60% by weight and more, the HCl content in the flue gas will be in the order of several grammes HCl/nm^3. The possibility that major quantities of HCl may be generated requires very careful selection of materials and imposes maximum requirements on the efficiency of the flue-gas scrubbers.

Apparently caused by HCl and supported by other aggressive volatile flue-gas components, corrosion damage was also temporarily encountered on system components which, due to their composition of materials, should have resisted this corrosive attack. Some parts made of Hastelloy C in the injection cooler, in the rotary scrubbers and in the droplet traps were completely destroyed after only a few thousand operating hours. Similar damage was also encountered in the heat exchanger and in the suction blower. These damage and malfunction problems have now been corrected through design changes and through the use of improved materials.

In the combustion of chlorinated hydrocarbons the formation of elementary chlorine through oxidation of HCl cannot be theoretically excluded. Chlorine represents a certain danger to metallic system components. The thermodynamic data of this oxidation process, which is referred to as the Deacon reaction, show that chlorine formation is strongly reduced with increasing temperature and increasing water content, but is facilitated with decreasing temperature and increasing HCl and oxygen concentration. At the usual combustion temperatures between 1,200 and 1,300°C, however, the theoretically possible chlorine quantity is only 10 mg Cl_2/nm^3 which is negligible.

Considerably more significant, however, is the question as to the change of equilibrium taking place as the flue gases pass through the ducts of the heat recovery boiler until they have cooled to approx. 300°C. In this temperature range the equilibrium concentration of chlorine is so high that the corrosion of the boiler and system components must be feared. It is a known fact that carbon as well as iron and copper oxides have a catalytic effect and accelerate the equilibrium. In fact, a concentration of 200 mg Cl_2/nm^3 has been measured in the flue gas during the incineration of copper-containing chlorinated hydrocarbons. The combustion space temperature was 1,100°C, and the flue gases passed the temperature drop from 1,100°C to 600°C in approximately 2 seconds. In addition, the catalytic effect of dust from the electrostatic filter on chlorine formation was studied under laboratory conditions. For these studies a mixture of 90% by volume of air, 9% by volume of water vapor and 1% by volume of HCl was passed through a reaction tube at 500°C filled with glass wool and dust from the electrostatic filter, and the chlorine content determined at the outlet. After a residence period of 15 seconds, chlorine contents up to 800 mg Cl_2/nm^3 were determined.

Similar reactions take place in the incineration of bromine and iodine-containing waste. As a result of the lower electron negativities of bromine and iodine, the unfavorable effect arises that the formation of the corresponding halogenated hydrocarbons will shift in favor of free halogens so that increasing quantities of free bromine and iodine are produced.

In order to avoid the problems in systems technology and apparatus involved in the possible occurrence of free halogens in the flue gas, it has been found advantageous to incinerate halogen-containing waste together with sulfur-containing waste. Apparently the SO_2 produced during this process will reduce the halogens present to the corresponding halogenides to a degree where not even traces of halogen can be identified by analysis. Therefore, the prerequisite for stopping the halogens in the flue-gas flow is to maintain a constant waste mix and an adequately great SO_2 concentration. As a result of this mode of operation it has been possible so far to avoid any corrosion damage by halogens.

Fig. 3—Bunker building for solid waste; delivery in tipping truck.

Incineration of polychlorinated compounds. Certain polychlorinated compounds may appear problematic from the point of view of incineration in that they are characterized by their increased thermal stability. Consequently, their complete incineration may require higher temperatures and longer residence times in the combustion zone. Our own studies in this field have shown that, at temperatures above 1200°C and minimum residence times of 1 second, it was impossible to identify any chlorinated compounds in the flue gas, the lower identification limit of the analysis being approximately 0.003 $\mu g/nm^3$.

Incineration of organic phosphorous compounds. The primary combustion product of organic phosphorous compounds is gaseous phosphorous pentoxide. This compound has extremely unfavorable chemical and physical properties for the process of an incinerator system. Phosphorous pentoxide is fairly volatile, its vapor pressure being 10^{-2} Torr at 300°C which is equivalent to 170 mg P_4O_{10} per nm^3, its melting point is 569° C and its boiling point 591°C. Being the anhydride of a strong tribasic acid, phosphorous pentoxide violently reacts with water even at elevated temperatures, forming metaphosphoric acid. Phosphates of varied basicity are formed in the presence of basic oxides or salts. At temperatures above 600°C reactions with airborne dust deposited on heat exchanger surfaces and on the internals of the electrostatic filters take place with the result that these loose deposits turn into sticky, firmly adhering and difficult to remove incrustations. This will result in increased pressure drop and reduced efficiency of the heat recovery boiler

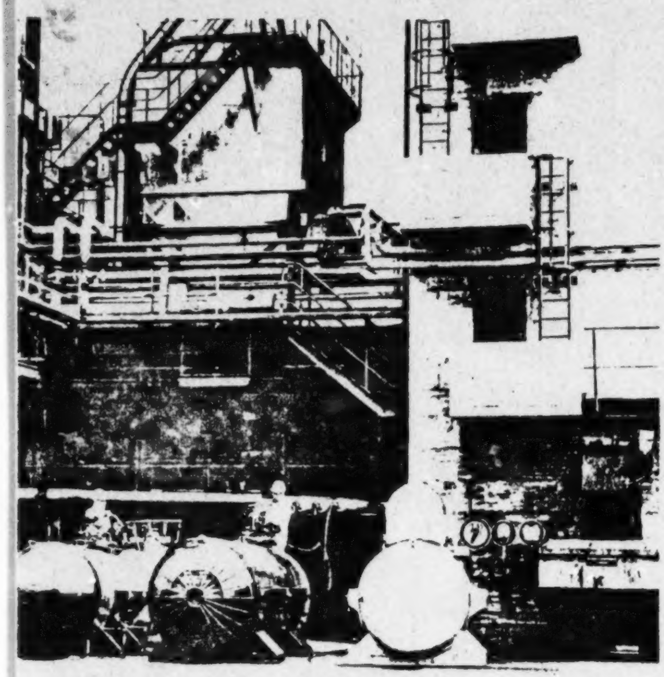

Fig. 4—Incineration of liquid waste from settling tanks.

and electrostatic air filters. In addition, reactions with the boiler walls cannot be excluded. The gaseous P_4O_{10} penetrates the dust deposits and reacts with the protective iron oxide layers on the boiler wall, forming iron phosphates. In addition, it has been observed that, due to the very small temperature interval between condensation point and melting point ($\Delta T = 22°C$), when the phosphorous oxide-containing flue gases cool, it will easily happen that very fine aerosols are produced which are only highly inadequately separated by conventional dust traps. Many experiments and design modifications were necessary in order to find a solution for these problems. In the meantime the process technology and the plant design have been adapted to the point where no emissions are observed even under surging P_4O_{10} loads.

Incineration of organic silicon compounds. Extremely fine silicon dioxide particles are produced during the incineration of organic silicon compounds. SiO_2 has a very high melting point (1713° C) and high electrical resistance (10^{12}-10^{13} Ω/cm). Both are adverse properties from the point of view of optimum electrostatic dust separation. As a result of the very high melting point the SiO_2 aerosols from the primary process will not agglomerate into larger particles, and the separation efficiency of the electrostatic filter is correspondingly poor. Due to the high electrical resistance, the electrical charge is transferred very slowly from the deposits to the separation electrodes. The SiO_2 deposits have the effect of a dielectric, impeding the electron flux between spray discharge electrodes and separation electrodes which is necessary for dust separation.

It is found in day-to-day operations that during the incineration of silicon-containing compounds the separation efficiency will drop below 30 percent of the usual value in spite of increased field strength. In these cases the perforated plates, the spray discharge wires and the separation plates of the electric dust filters are subsequently covered with dust deposits up to 10 mm thickness. Normal vibrating devices are inadequate for the removal of this type of dust accumulation. Ninety-nine percent of this dust consists of SiO_2; its density has been determined at 0.05 g/cm^3. Consequently, the incineration of organic silicon compounds usually requires extensive manual cleaning work in the electrostatic filter systems.

This is another case where the process was optimized through systematic experiments and some redesign to the degree where malfunctions of the type described above no longer occur.

Ash with heavy-metal content. One problem of special significance is the heavy-metal content of slag and ash. In addition to metal compounds which are insoluble in water, a great number of soluble metal compounds in the form of oxides, chlorides or sulfates are produced during the incineration of chemical waste. These compounds, contained in the slag and ash, are easily eluted when the slag or ash is flushed from the system, and thus may get into the waste water. The prevention of this contamination requires additional methods to reduce the heavy-metal content of scrubbing and slag water. One such method, for instance, is the precipitation of heavy-metal ions with milk of lime, forming hydroxides which are almost insoluble in water and can be filtered.

Another problem is the volatility of certain metal compounds. Some metal oxides and chlorides have such a high vapor pressure at temperatures from only 150 to 350°C that they will pass the electrostatic filters and, unless there is a flue-gas scrubber, would condense only after further cooling and discharge into the atmosphere. These include predominantly the oxides of arsenic, selenium and phosphorous as well as the chlorides of antimony, arsenic, iron, mercury, tin, cadmium, bismuth, zinc and tantalum. Since some of these compounds are highly toxic, the flue-gas scrubbers must be extremely efficient. For instance, a mercury content of only 0.1% by weight in waste would be sufficient to cause an emission of approximately 120 mg $HgCl_2/nm^3$ in the exhaust gas. Or, during the incineration of waste containing 0.1% by weight of $CdCl_2$ and provided that all of the easily soluble cadmium chloride is dissolved in the slag water, the waste water, based on a realistic waste water ratio of 2 m^3 per ton of waste incinerated, would contain approximately 500 mg $CdCl_2$/liter!

WASTE ACCEPTANCE

Waste generated in Bayer AG plants is first reported by the operating departments to the anti-pollution and waste disposal department, using an incineration permit accompanied by a 5 kg sample. This incineration permit includes data on the quantity, the precise designation and characteristic components of the waste to be incinerated. Other important information for waste disposal include the type of packaging and/or delivery to the plant, the date of delivery, the state of aggregation of the waste, its combustibility, the flash point, the ignition temperature, the calorific data, its behavior upon heating, its boiling point, gas generation, reactivity with water, toxicity, any odors generated and the hazard class according to the Flammable Liquid Directive (VbF). Within the waste disposal department the waste acceptance and inspection laboratory group, on the basis of this information and if necessary its own laboratory studies, determines the technically and economically optimum waste disposal method (incineration with or without flue-gas scrubbing, incineration on the high seas, surface or underground disposal), completes the study by assigning an inspection number and communicates the result to the operating department concerned. If the waste disposal department proposes the disposal of waste by incineration, the waste will be delivered to the plant together with a waste way bill which lists predominantly the quantity, number and type of containers, the inspection number and the materials classification code. This materials classification code is important for computing the incineration cost. Practical experience has shown that a rough classification of combustible waste into eight materials classes is best. The incineration cost per materials class varies from DM 165/ton for liquid non-chlorinated waste to DM 885/ton for waste in small containers of highly variable content.

On the basis of the materials classification code the incoming waste is channelled to certain collection points by a control center. Solid halogen-, sulfur- and/or phosphorous-containing waste is collected in a bunker building. This bunker building includes four chambers having a capacity of 200 m^3 each. On the basis of their basicity, neutral, basic or acid wastes are segregated and collected in a certain chamber each. The fourth chamber is available for special waste types. Liquid halogen-, sulfur- and/or phosphorous-containing waste is either incinerated directly from settling tanks (maximum capacity 10 m^3) or collected in larger tanks (capacity approx. 400 m^3) for intermediate storage. The method used is decided on the basis of the quantities generated and the chemical compatibility of the different waste types. Highly reactive, decomposing and/or generally difficult to handle waste is delivered in combustible plastic drums whenever possible (capacity 60 to 100 liters), handled via a separate drum elevator and dropped with drum into the rotary kiln for incineration.

NO. II INCINERATOR SYSTEM

The process concept for the No. II incinerator system was developed on the basis of the specific waste situation prevailing at Bayer's Leverkusen plant with due consideration to the theoretical studies above. The practical experience acquired in several years of operation on No. I incinerator system proved highly advantageous for the detailed planning effort.[2]

One new feature of this process is the multi-stage flue-gas scrubber system. Other design modifications included the configuration of the ash bunkers, the lay out and design of the afterburner chamber and the design of the heat recovery boiler.

The process schematic of No. II incinerator system is shown in Fig. 2. The functions of the individual system components are described below.

The most important technical specifications of this system have been compiled in the following table:

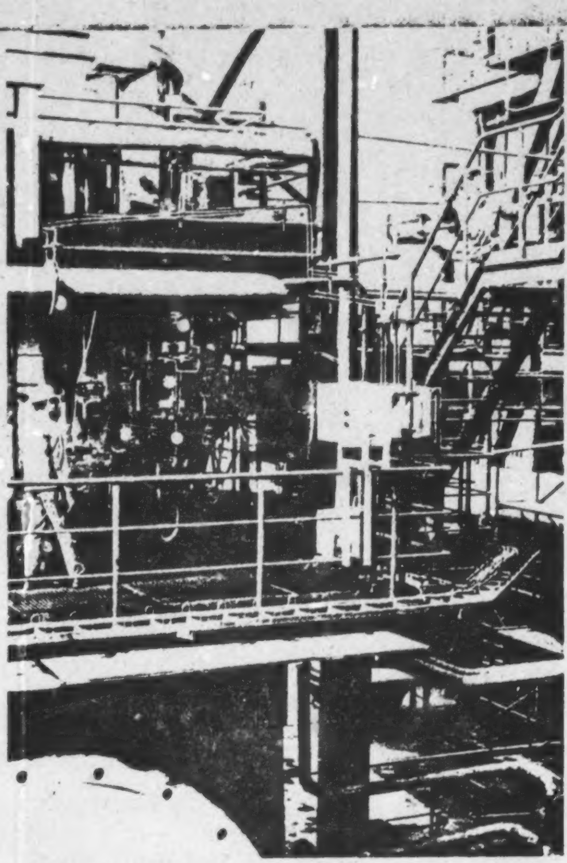

Fig. 5—Rotary kiln with upright, 2-duct afterburner chamber.

Bunker building		
Waste acceptance	4 chambers	200 m^3 capacity per chamber
Waste charging system	1 grapple	0.8 m^3 capacity
	1 plate conveyor	3-4 ton/hour
	2 slide gates	approx. 2-minute cycles
	1 charging ram	
	1 drum elevator	capacity 2-3 ton/hour
Rotary kiln		length 13.5 m
		diameter 3.5 m
		maximum thermal load 15 Gcal/hr (approx. 60 GJ/hr)
Solid waste incineration (see above)		
Liquid waste incineration	various settling tanks	capacity 3-5 m^3
	tank farm	several tanks
	1 sustaining burner	capacity 300 kg/hr
Sludge incineration	1 injector	
Combustion air	1 blower	capacity 37,000 m^3/hr
Cooling air	1 blower	capacity 5,400 m^3/hr
Flue-gas outlet temperature		1,100 to 1,200° C
Afterburner chamber		
Secondary combustion	various settling tanks	capacity 1-5 m^3
	tank farm	several tanks
	3 liquid burners	capacity 300 kg/hr per burner
	1 booster burner	capacity 50 kg/hr
Residence time		2-4 secs.
Flue-gas flow rate		40,000-50,000 nm^3/hr, max. thermal load 20 Gcal/hr (approx. 80 GJ/hr)
Flue-gas outlet temperature		1,200-1,300° C
Heat recovery boiler		
Heat recovery	4 ducts	20 ton steam/hr, 38 bars, 350° C
Flue-gas outlet temperature		300° C
Electrostatic filters		
Dry dust removal		max. 20 kg dust/hr
Flue-gas scrubber		
Cooling and HCl separation	1 injection cooler	6-8 m^3 water/hr
Residual dust separation	2 rotary scrubbers	5-25 m^3 water/hr
Alkaline scrubber	1 jet scrubber	2-12 m^3 water/hr
Sulfite oxidation	2 columns	
Exhaust air outlet temperature		60° C
Waste-air heating	2 heat exchangers	
Suction blower	1 ducted-impeller blower	capacity 60,000 m^3/hr, drive rating 335 kW
Stack	insulated steel tube	height 100 m
	instrumentation and recording devices	waste-air outlet velocity 12-15 m/sec

CHARGING SYSTEMS

Solid waste charging. Solid waste is predominantly delivered in tipping lorries and collected in a sealed bunker building. Bulky materials are crushed in an impact mill. The charging hopper located above the rotary kiln inlet is charged by a grapple which is controlled from a fully air-conditioned operator cab which is sealed against the bunker space, using TV cameras and TV screens in a partially automatic, partially manual operation. The rotary kiln inlet is sealed against the bunker space by a lock fitted with two sliding gates. When the inclined sliding gate (in the drop chute of the rotary kiln inlet) is closed, a horizontal sliding gate located in the charging hopper will open.

A continuously operating plate conveyor belt located below moves the waste into the drop chute and deposits it on the inclined sliding gate. After a certain cycle time the horizontal sliding gate will open and the waste will drop down an inclined chute into the rotary kiln inlet. Any waste remaining on this inclined chute is pushed down by a ram.

Liquid waste charging. Liquid waste is delivered in sealed settling tanks having a capacity up to 10 m³. Part of the liquid waste is incinerated directly from these settling tanks while another part is collected for intermediate storage in larger tanks (400 m³ capacity) prior to incineration.

The transport of this liquid waste to the individual incineration points is accomplished via pumps or under nitrogen pressure (3 bars). Waste oil containing solids is first purified in a screening machine. The screen residue with a particle size of over 2 mm is moved by a compressed-air conveyor system (Gulliver gun) via a pipe line directly into the rotary kiln. Some of the waste delivered in settling tanks requires liquefaction through heating prior to combustion so that it can be pumped and atomized in the burners.

Steam outlets at up to 30 bars pressure are available for this purpose. After removal of the waste from the settling tanks through pressure, the tanks are de-pressurized via gas lines terminating in the afterburner chamber via intermediate safety devices. Waste liquids of low calorific value are atomized together with waste having high calorific value in multiple-fuel burners and incinerated. Atomization is accomplished either with steam or with compressed air.

These burners are located in the face side of the rotary kiln (1 burner) and in the wall of the afterburner chamber (3 burners, 1 booster burner). Burner monitoring is accomplished via a temperature sensor system. When the temperature drops below 1050°C a booster burner fired with natural gas is ignited, supporting the main burners. If the temperature continues to drop below 950°C, the fuel feed is interrupted by quick-action valves.

Charging of problematic waste in small containers. A separate system is available for charging the system with waste in small containers (cans, drums) which consist predominantly of an elevator, a roller conveyor, a lock with two sliding gates and a tilting table from which the small containers are dropped into the rotary kiln. This charging system is interlocked by the control system so that these small containers can be dropped into the rotary kiln only when the inclined sliding gate is closed. This insures that there will not be any interference between the drum charging system and the solid waste charging system.

Rotary kiln, afterburner chamber. The rotary kiln has a length of 13.5 m and an outer diameter of 3.50 m. The ceramic refractory liner has a thickness of 0.25 m. Consequently, its inner diameter is approximately 3 m. The rotary kiln is inclined 3 percent toward the outlet end.

The average rotating speed is approximately 9 revolutions per hour. It is infinitely variable between 7 and 24 revolutions per hour. The residence period of the waste in the rotary kiln is approximately 1½ hour. The internal temperatures reach 1,200 to 1,300°C. The hottest zone is located in the 7 to 11 m range. This is the zone where the strongest corrosion and erosion attack takes place. It is attempted to keep this attack within justifiable limits through the selection of extremely high-quality refractory materials and the continuous presence of a protective slag layer. At the discharge from the rotary kiln the slag drops into a water-filled plate conveyor slag removal system. The slag is free of any pollutants and can be deposited at a disposal site without any danger. The combustion air at a rate of approx. 40,000 nm³/h is aspired from the bunker building and injected into the rotary kiln inlet below the solid waste charging system. The gross thermal rating of this rotary kiln is approx. 60 GJ (15 Gcal).

A circular, 2-duct, upright afterburner chamber is placed immediately downstream of the rotary kiln. Its height is approx. 9 m and its inner diameter 4.10 m. Both ducts are provided with a liner of high-temperature ceramic refractories. At approximately half the height of the first duct three liquid burners with an average thruput of approximately 300 kg/h per burner are distributed over the circumference.

In continuous operation this arrangement will achieve intensive admixture of the flue gases, combustion temperatures up to a maximum of 1300°C and a residence period of 2 to 4 seconds. Secondary air nozzles are installed above these burners for safety reasons through which additional combustion air can be injected. The entire inner space of the rotary kiln can be inspected from a port located in the base of the first afterburner duct. This has special advantages for the continuous inspection of the rotary kiln refractory liner and the protective slag layer in the kiln.

The second duct serves as an abatement chamber, and its bottom end has an ash collection space. This space can be cleared at certain time intervals through a port of several square meters area which is closed by four bulkheads; a front end loader is used for ash removal. Continuously operating conveyor devices have not been found feasible at this point. The afterburner chamber is designed for an over-all thermal rating of 80 GJ (20 Gcal).

Heat recovery boiler. The flue gases departing from the afterburner chamber at approx. 1200°C are cooled to about 300°C in the heat recovery boiler, generating approx. 20 tons of steam per hour at 38 bars and 350°C. This heat recovery boiler is an upright 4-duct boiler type. The first two ducts are empty ducts with radiative heating

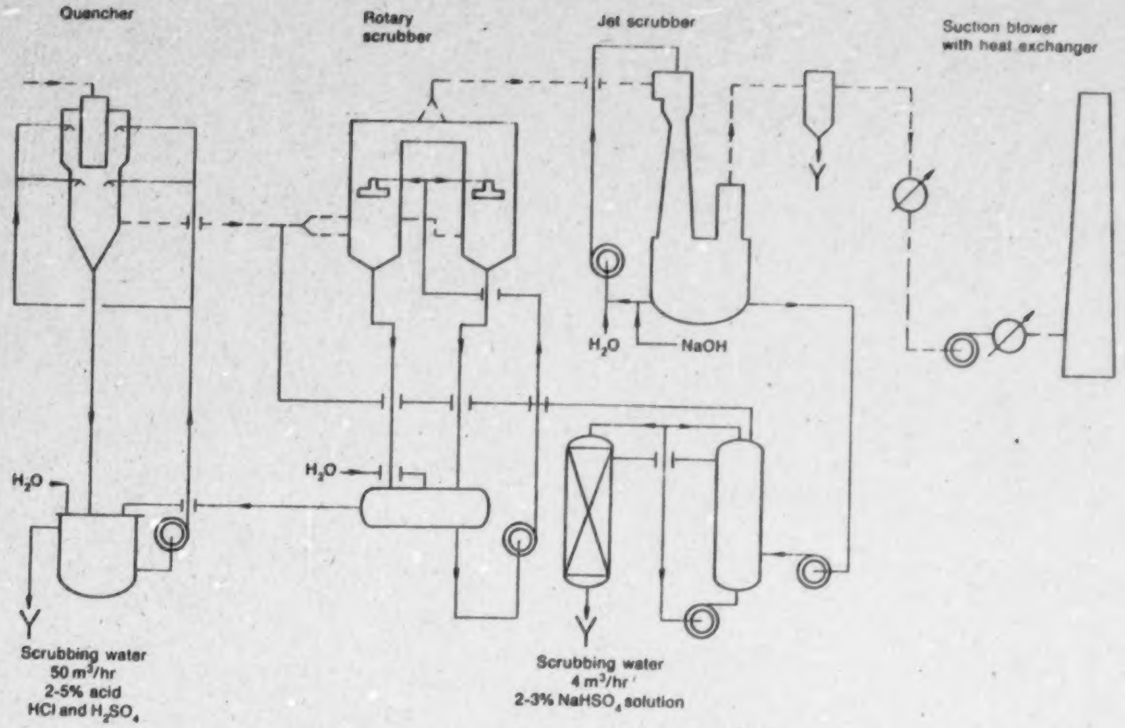

Fig. 6—Schematic of the flue-gas scrubber system.

surfaces. The last two ducts contain superheater, evaporator and economizer.

These boiler ducts have been made of finned tubing cooled by natural circulation. The contact heating surfaces have been welded from square tubing, forming smooth elements that are easy to clean with soot blowers, and connected to a forced circulation cooling system. The rotary kiln charging system and the heat exchangers used for heating the scrubbed flue gases are also installed in this cooling circuit.

Flue-gas scrubbers. In addition to CO_2 and H_2O the combustion of chemical waste produces predominantly SO_2, HCl, NO_x and dust as well as minor quantities of HF, SO_3 and P_4O_{10} whose quantities in the flue gas have been limited under the Anti Air Pollution Directive (TA-Luft) so that most of them must be scrubbed from the flue gas.

The concept definition for the flue-gas scrubbing system was based on the assumption that the flue gases will contain an average of 10 g HCl/nm³, 2.5 g SO_2/nm³ and 2 g dust/nm³, and that multiples of these concentrations may easily occur under peak loads. The quantities of HF, NO_x, SO_3 and P_4O_{10} were considered to be of minor significance.

The dry portion of the combination dry-wet flue-gas scrubbing system consists of the electrostatic filter and the 3-stage wet portion of the injection cooler (quench), the two rotary scrubbers in a parallel configuration and the jet scrubber.[3]

The majority of the dust is precipitated from the flue gases at approx. 300°C in the electrostatic filter. The filter efficiency is approx. 90-95%. The precipitated dust is removed by a scraping conveyor belt, collected in a covered tipping lorry and deposited at a solid-waste disposal site. This procedure has the advantage that any heavy metals contained in the dust and/or precipitated together with the dust cannot get into the subsequent wet scrubbing system where it would be dissolved in the form of chlorides or sulfates which could interfere with the biological treatment process of the liquid-waste treatment plant.

In the injection cooler the flue gases arriving from the electrostatic filter are cooled from 300°C to a level of 60-70°C and, at the same time, the majority of the HCl is separated. The cooling and scrubbing water required for this purpose is re-circulated. The evaporation losses are compensated by 6-8 m³/hr make-up water. The design of this section of the system and the materials used have been selected in accordance with the enormous thermal and corrosive loading of this section. The HCl concentration of the departing scrubbing water varies from 2-5 percent.

From the injection cooler the flue gas passes into two parallel rotary scrubbers. In these scrubbers the flue gases pass through a dense cloud of very fine water droplets generated by two rapidly rotating paddle-wheels.

These rotary scrubbers have three functions: (1) separation of any residual dust and extremely fine dust as well as volatile metal compounds; (2) separation of sulfuric acid aerosols which may be generated in considerable

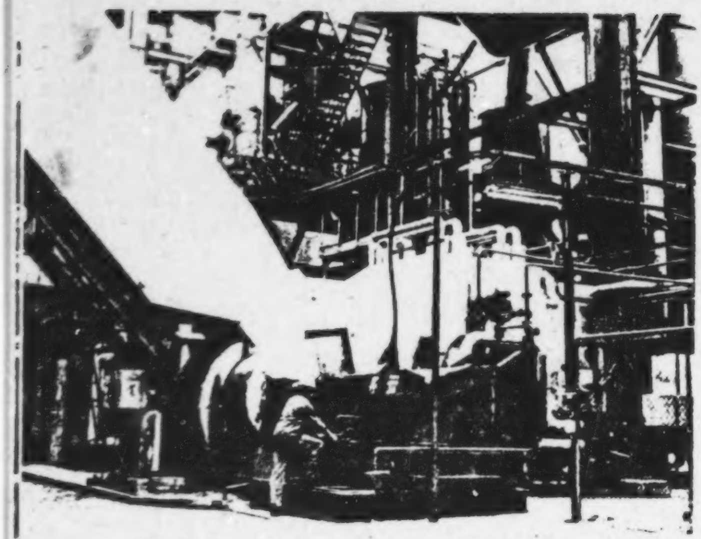

Fig. 7—Suction blower with heat exchanger for reheating the purified flue gases.

quantities in the injection cooler when the flue gases have certain compositions; (3) separation of the total dust if the electrostatic filter fails or if dust penetration occurs under excessive loads.

The scrubbing water is collected in a manifold and pumped out from this point. 2-5 m³/hr fresh water is fed into this manifold in order to prevent any sludge accumulation. The overflow is passed to the collection point for transport to the liquid-waste treatment plant. Compared to other comparable scrubbers this rotary scrubber has the advantage of being insensitive to gas flow rate fluctuations; ensuring a high solids concentration (up to 200 g/liter) and having a lesser pressure drop (approx. 50 mm WC).

The latter effect was decisive for the decision in favor of this scrubber type. It meant that a flue-gas suction blower of lower pressure (400 mm WC), slower speed and lesser noise pollution could be installed.

Downstream of the rotary scrubbers the jet scrubber, using a weakly alkaline medium, is the third scrubbing stage. In this scrubber especially the SO_2 in addition to residual HCl, chlorine and NO_x are removed. In principle this scrubber is an over-dimensioned water jet pump. The scrubbing water is injected in the direction of the gas flow at a pressure of 3-6 bars. The downward velocity of the scrubbing water is 25-35 m/sec, that of the flue gas 10-20 m/sec.

As a result the scrubber automatically aspires the flue gas. The small pressure gain is adequate to overcome the internal drag. The scrubbing water is collected in a manifold and re-circulated. Scrubbing water losses are compensated by approx. 2 m³ fresh make-up water per hour. The scrubbing water pH value is maintained constant at a certain adjustable value by means of a measuring and control device. The pH value of the scrubbing water is adjusted by adding sodium hydroxide solution.

The Na_2SO_3 and $NaHSO_3$ produced through reaction of SO_2 with sodium hydroxide in this jet scrubber must be oxidized into Na_2SO_4 prior to discharging the scrubbing water into the liquid-waste treatment facility. A specially developed 2-stage facility is used for this purpose where the oxidation is accomplished instantaneously at temperatures between 70 and 90°C. The discharged scrubbing water contains approx. 5% Na_2SO_4 and can be passed to the liquid-waste treatment plant together with the overflow from the injection cooler and the rotary scrubbers.

The entire wet section of the flue-gas scrubbing system is provided with an internal rubber liner for corrosion protection. Numerous instrumentation and control points monitor and control the scrubbing process. The cost of flue-gas scrubbing is approx. DM 100 per ton of waste incinerated.

Flue-gas drying and heating. In order to prevent condensation and corrosion in the stack and to ensure the rapid dispersion of the purified waste air in the atmosphere, two droplet traps and two heat exchangers (flue-gas heaters) have been installed between the jet scrubber and the stack. The first droplet trap is located immediately downstream of the jet scrubber and the second upstream of the first heat exchanger.

Waste-air heating is accomplished in two stages. The suction blower required to produce the necessary negative pressure in the different system components and to move the purified waste air into the atmosphere via an insulated stack of 100 m height is located between the two heat exchangers. The hot water required for the heat exchangers is obtained from the natural circulation of the heat recovery boiler.

This flue gas reheating process requires approx. 5 tons hot-water steam per hour, equivalent to 35,000 tons steam per annum at a cost of approx. DM 0.5 million for an average of 7,000 hours of operation per annum. If this reheating system were eliminated, the incineration cost could be reduced by 5-10%.

Efficiency. The energy efficiency of this system is computed as follows: under normal load approx. 1.8 tons of solid waste and 1.2 tons of liquid waste as well as approx. 0.6 tons of small-container waste are incinerated per hour. This waste has an over-all calorific value of approx. 83.7 GJ (20 Gcal). Out of this quantity, 41 GJ/hr (9.8 Gcal/hr), equivalent to 49%, is consumed for steam generation, and 9.2 GJ/hr (2.2 Gcal/hr), equivalent to 11%, is required for re-heating the purified waste gases. The remaining 40% includes 29.4% over-all heat losses (radiative losses on the rotary kiln, the afterburner chamber and the boiler, heat losses in the injection cooler and heat removal via the flue gases), and 10.6% for the operational uses of the plant.

ANTI-POLLUTION REQUIREMENTS

The license granted by the Düsseldorf Licensing Authority on Dec. 31, 1974, established the following maximum emission values for the No. II incinerator system:

SO_2	1,250 mg/nm³ waste air
NO_x	1,000 " " "
HCl	100 " " "
HF	10 " " "
Dust	100 " " "
O_2	11% by volume

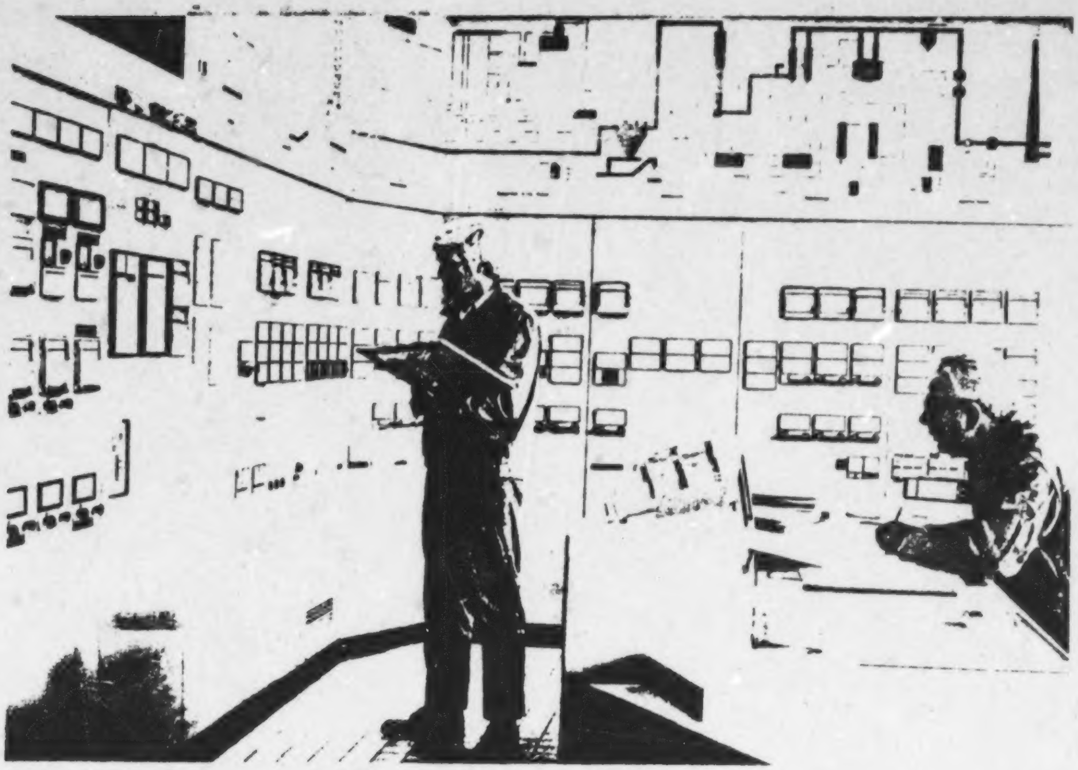

Fig. 8—Control center for the No. II incinerator system.

These components must be measured continuously for anti-pollution monitoring. For some components the monitoring is accomplished by means of continuously recording apparatus.

Systematic flue gas analysis under different loads and modes of operation was accomplished during the period from 6,000 to 8,000 hours of operation in order to study the efficiency of the flue-gas scrubbing system. The following results have been achieved:

Flue-gas component	Normal load (in mg/nm³)	Peak load (in mg/nm³)
SO_2	300	800
NO_x	400	up to 1000 and more
HCl	50	100
HF	3	5
Dust	20	100

On the whole the anti-pollution limits are maintained. They are occasionally exceeded with respect to NO_x. This has not been due to deficiencies in the apparatus or in the process, but to the fact that the physical and chemical properties of nitrogen oxides render any absorption very difficult. To this date no scrubbing process has been developed where separation efficiencies are achieved which are comparable to those achieved when scrubbing SO_2 and HCl.

In addition, the license requires all waste water and scrubbing water to be treated in a biological liquid-waste treatment plant.

Under normal operating conditions the afterburner chamber must be operated at a minimum temperature of 1000°C and a minimum residence period of 0.3 secs. The minimum temperature must be increased to 1200°C for the incineration of polychlorinated compounds.

The afterburner chamber temperature must be monitored by continuously recording apparatus. If the temperature drops below 1000°C, the charging system of the rotary kiln must be stopped.

ACQUISITION COST, PLANNING AND ERECTION TIME

The investment to acquire a capacity of 25,000 tons per annum of chemical waste amounted to DM 27 million. The system concept was developed jointly with L. & C. Steinmüller GmbH, D-5270 Gummersbach, who were also the designers and contractors for the construction of the facility. The planning period extended over two years. Erection required one year. During the three years of planning and construction this project secured approximately 100 jobs. The operating cost is DM 10 million per annum. Consequently, the average incineration cost is approx. DM 400 per ton of waste.

After trial operation of approx. 7,000 operating hours the No. II incinerator system of Bayer AG's Leverkusen plant was commissioned for regular service in November 1977. This system has passed the performance tests, achieving the specified operating parameters and has demonstrated its efficiency. It was presented to the public in a brief ceremony on Jan. 18, 1978.[4]

The trend of the waste situation during the next one or two decades can be estimated on the basis of two facts:

1. The Leverkusen plant has reached its maximum expansion level, and
2. Low-waste technologies are used with preference when new products are marketed.

The conclusion may be drawn that the amount of production waste of the type described in this article will not increase significantly in the short run. Therefore, the construction of a third incinerator system is not contemplated.

POSTSCRIPT

One important item in the planning concept was the company requirement for a maximum of continuous mixing and transport of the different waste materials with respect to their calorific value and quantity in order to create uniform thermal conditions in the combustion spaces. In this respect a problem was created by the so-called small waste containers, cans or drums of 60 to 100-liter capacity and having a great variety of contents.

These small containers are filled with solid, paste and liquid production or laboratory waste in pure or mixed form whose calorific value fluctuates from 0 to 10,000 kcal/kg. The composition of these small container wastes may vary greatly. Often the contents are toxic, frequently they are not admixable, some of them will burn very slowly, but most of them spontaneously, and they sometimes react with great sensitivity to air and humidity.

The general practice of dropping the small containers into the rotary kiln without emptying them has process disadvantages. Occasionally there will be deflagrations with strong soot generation and excessive thermal and mechanical loading of the kiln refractories resulting from this practice.

In order to prevent these defects, paste and liquid small-container contents should be pressed into liquid nitrogen, granulated under nitrogen shielding, mixed and removed from the nitrogen bath into the rotary kiln by a conveyor system.[5]

This type of system would have been an elegant solution for all process problems arising in conjunction with these small-container wastes. Unfortunately, it would have caused some difficulties which were not accurately predictable and/or could not be exactly determined through preliminary studies:

1. The freezing characteristics of different organic wastes and waste mixtures vary greatly. One special disadvantage is that certain groups of materials will form continuous layers of incrustations floating on the nitrogen surface or adhering to the inner walls of the containers which do not settle on the bottom so that they cannot be removed and will gradually clog the system. Other groups of materials will freeze into minute crystals suspended in the liquid nitrogen bath, gradually enriching and forming a thick paste of crystals which finally agglomerates and blocks the conveyor system.
2. The small-container waste is mostly highly heterogeneous. Plastic film, plastic beakers, leather and rubber gauntlets as well as glass bottles are frequent accompanying products. Where these materials get into the liquid nitrogen bath, they will quickly clog the granulator and the transport screw. The necessary repairs are time-consuming and require many man-hours and, moreover, they are not entirely free of danger since reactive mixtures or explosive vapors/air mixtures can form during thawing, or toxic substances may be released.

Since these difficulties involved in retention of the concept could have been resolved only at additional enormous effort in terms of research and process development, if at all, it was attempted to optimize the combustion conditions through design modifications in the incinerator system itself and through process modifications so that even these problematic waste types could be properly disposed of without the disadvantages named above. These experiments which might be the subject of a later article have been successful every step of the way so that these problems may now be considered resolved.

This example was given to indicate that the apparently direct approach will not always yield the desired success. It may be possible that, in view of the increasing complexity of the problems, detours will become increasingly unavoidable which will be associated with high cost and will be very time consuming.

About the authors

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PETER REHER *is group engineer responsible for the waste disposal and water pollution control plants at Leverkusen for Bayer AG. Dipl.-Ing. Reher studied process engineering at the Technical University in Aachen and first joined Uhde in Dortmund. He first joined Bayer AG in the planning and coordination of the construction of sulfuric acid plants and in their operation.*

M. SCHOEN *is head of Incinerator Plant II at Leverkusen for Bayer AG. Dr. Schoen studied chemistry at the Humbolt University and the Technical University of Berlin. He joined Bayer AG in the Enamel Department and became head of the laboratory for industrial scale manufacture of glass fiber products.*

LITERATURE CITED

[1] Fabian, H. W. and M. Schön, Thermal Waste Treatment (Thermische Behandlung der Abfallstoffe), Paper presented at the first Special Waste Seminar of the Management Information Centre, Verlag Moderne Industrie Publishers, Munich, 29/30 September 1977.

[2] Fabian, H. W. and H. O. Weber, The New Waste Incineration System of Farbenfabriken Bayer AG, Leverkusen (Die neue Rückstandverbrennungsanlage der Farbenfabriken Bayer AG, Leverkusen), published in Brenstoff-Wärme-Kraft (BWK), Volume 19 (1967), No. 10, pp 484-486.

[3] Reimer, H., Flue-Gas Scrubbing in Waste Incinerator Systems Rauchgaswäsche nach Müllverbrennungsanlagen), published in VGB Kraftwerkstechnik, Volume 53 (1973), No. 11, pp 735-742.

[4] Fabian, H. W., Incineration of Chemical Waste (Verbrennung von Chemieabfällen), published in Umwelt No. 3/78, pp 153-158.

[5] Gromotka, H., New Processes for the Thermal Treatment of Polluting Industrial Waste (Neue Verfahren für die thermische Behandlung von umweltschädlichen Industrieabfällen), published in Energie und Technik, 1974, No. 6, pp 131-134. ■

Annex V Commercially available hazardous waste incinerators in the United States (as of August 1979)

Attached is a state-by-state breakdown of hazardous waste incinerator capacity in gallons per day. There is also a listing of each incinerator with information (if available) on:

- type of incinerator
- capacity
- actual operation time or estimated down time
- type of waste incinerated
- cost of incinerator alone or entire installation

State	Capacity gal/day x 10^3 (assuming continuous operation)	% of day currently incinerating	Actual amount currently incinerated per day
Alabama	7, 5		
Arkansas	70	75 %	52, 5
California	4	90 %	3, 6
Georgia	2, 9		
Hawaii	2, 4	14 - 19 % (~16, 5)	(34 - 46) 4
Illinois	2, 4	83 %	1, 99
Indiana	3, 3		
	20	10 %	2
Kentucky	38		
Louisiana	30		
Maine	5, 5	86 %	4, 6
Maryland	1, 3		
Massachusetts	24	56 %	13, 4
	4, 0	70 %	2, 8
Michigan	66		
	2, 4		
New Jersey	30	90 %	27
New York	13, 5	33 %	4, 4
	20, 0	33 %	6, 6
North Carolina	5, 8		
Ohio	51, 2	85 %	43, 5
South Carolina	48		
	12		
Tennessee	3, 1	93 %	2, 9
Texas	30	90 %	27
	10	92 %	9, 2
Virginia	17	8 %	1, 4

Total = 793, 500

~ 500, 000 gal/day

Assumption

9, 000 BTU/lb.

7. 5 lb/gal.

[illegible]

[illegible]

ALABAMA 1 To open in 4 to 6 weeks.
Waste Management Inc. of Alabama
Emelle, Alabama
205-652-9531

rotary kiln
5-10,000 gal/day depending on the BTU value
anticipate operation 5-6 days/week, 24 hours/day
liquids only: chlorinated hydrocarbons, solvents, alcohols
$350,000

ALASKA none
ARIZONA none

ARKANSAS 1 Two incinerators on one site - rotary kiln currently being tested by EPA.
ENSCO
P.O. Box 1975, American Oil Road
El Dorado, Arkansas 71730
501-863-7173

I liquid injection
600,000 gal/month
operate continuously except for manintenance, down time = 8 days/month
organic waste up to and including hexachlorocyclopentadiene
$ 3 x 10^6

II rotary kiln (not commercially available yet)
60 x 10^6 BTU/hour
any liquid organic waste, solid organics in drums, PCB's if approved by EPA
$ 1.1 x 10^6
[Entire installation cost: $5-7 x 10^6]

CALIFORNIA 1
I.T. Environmental Corp.
4575 Pacheco Blvd.
Martinez, Calif. 94553
415-228-5100

liquid vent gas incinerator
4000 gal/day maximum, dependant upon BTU value
down time = 3 days/month
only liquids: solvents, alcohols, oils, contaminated fuels
20 x 10^6 BTU/hour recovered heat

COLORADO none
CONNECTICUT none
DELAWARE none
FLORIDA none -- one may open in Dade County in the near future

GEORGIA 1

Southeastern Waste Treatment, Inc.
1025 New South Harris Street
Dalton, Georgia
404-278-0091

rotary kiln
120 gal/hour
operate continuously except for maintenance
industrial solvents, limited to 16% Cl by weight
$ 200,000

HAWAII 1

Energy Recovery Systems
Campbell Industrial Park
Oahu, Hawaii
808-531-0182

liquid waste incinerator
100 gal/hour
operate 24-36 hours/week
waste oil, alcohols, torpedo fuel

IDAHO none
ILLINOIS 1

Interstate Pollution Control
1525 9th Street
Rockford, Illinois 61101 (815-964-2058)

multiple chamber liquid injection (Greenley & Hansen - manufac.)
150 gal/hour
operate 24 hours/day, 6 days/week, 50 weeks/year
waste oil, cyanide plating waste

INDIANA 2

Prenco
South Bend, Indiana
219-272-7584
(located on city land)

liquid injection
75 to 200 gal/hour
operate continuously except for maintenance
liquid wastes: liquid soluble oils
$ 1.5 x 10^6 (entire installation)

INDIANA continued

Seymour Recycling Corporation
G Avenue West
Seymour, Indiana 47274
812-522-4051

2 stationary liquid injection incinerators
Envirotech 250 - $\$.5 \times 10^6$ (1,000 gal/hour)
" 150 - $ 250,000 (250 gal/hour)
Accept all liquid wastes except PCB's and pesticides
total capacity= 20,000 gal/day
operate 10% of year - would operate more if there was increased demand
sells 30-40 gal/day to Portland Cement Co. for fuel

Note: shut down meanwhile

IOWA none
KANSAS none

KENTUCKY 1 rotary kiln to be tested in Sept. 1979
L.D.D., Inc.
Calvert City, Kentucky
502-395-7515
(*expect to triple their capacity by next year*)

I liquid injection (2)
15-24,000 gal/day (mean = 18,000)
operate continuously except for maintenance
cost of each unit = $500-800
burn "clean" waste only (only have particulate control)

II rotary kiln with liquid injection
20,000 gal/day
$\$1.2 \times 10^6$
chlorinated waste - will apply for a PCB license

LOUISIANA 1

Rollins Environmental Services
P.O. Box 73877
Baton Rouge, Louisiana 70807
504-778-1234

rotary kiln
30,000 gal/day
operate continuously except for maintenance (10 % down time)
all wastes except radioactive and PCB's
(are in the process of applying for a PCB permit)
can change the dwell time and temp. to achieve maximum destruction
maximum achievable temp. is 2500°
cost of plant in 1969 was 4 million, by now it has probably tripled

MAINE 1

Union Chemical Company
Union, Maine 04862
207-785-2625
Dr. Ray Esposito

I conventional boiler
20 gal/hour
flammable waste
currently operates 20 hours/day, 4 days/week
by Thanksgiving, the capacity will increase to 2,880 gal/week (i.e., 6 days/week)

II by Thanksgiving they hope to open an incinerator in South Hope, Maine
fluidized bed
5,000 gal/day (30,800 gal/week)
flammable and chlorinated wastes (2:1)
continuous operation; down time= 7 weeks/year

MAINE -- continued
Martin Marietta Co. in Rockland, Maine have a lined rotary kiln that they use in cement manufacture. The Maine Dept. of Environmental Protection is exploring the feasibility of destroying PCB's in this incinerator. Maine is currently storing PCB's.

MARYLAND 1 To begin operation week of Sept. 3, 1979.
Multi-Chem Corp.
5101 Andard Ave., Bldg. #610
Baltimore, Maryland
301-484-8199
Ronald Scott

liquid injection (automatic loader - Model: Ecpect 400E)
400 lbs/hour (1,280 gal/day)
pathological, chemical (e.g.,alcohols), and a small amount of medical wastes
incinerator cost = $35,000 not installed
serve an area 200 miles in radius from Baltimore

MASSACHUSETTS 2
Cannon Engineering
1st Street.
Bridgewater, Massachusetts
617-697-3344

liquid injection
1,000 gal/hour
operates 400 hours/month
oils,solvents,aqueous solutions
total cost = $450,000 (incinerator only = $200,000)

Recycling Industries
385 Quincy Avenue
Braintree, Massachusetts 02184
617-848-0612

I liquid injection
100 gal/hour, 16 hours/day (80 hours/week)
non-chlorinated solvents, oil-water emulsions
no scrubber

II stationary kiln (for solids)
500 lbs/hour, 16 hours/day (80 hours/week)
solid organic chemicals, hospital wastes, security matter

MICHIGAN 2

Liquid Disposal Co.
3901 Hamblin Road
Utica, Michigan
313-739-2727
Mr. Brinkman

liquid injection
2,500-3,000 gal/hour
operates continuously except for maintenance
paint solvents, cleaners, pesticides, watery slurry
total cost = $\$2 \times 10^6$ (incinerator only = \$250,000)

Al Disposal
400 Broad Street
Plainwell, Michigan 21330
616-685-9801

the incinerator shut down 3 months ago, however, it may begin operation again in Sept. 1979
100 gal/hour
hydrocarbons, liquid wastes

FUTURE: Floyd Wallace applied for a permit for a high temp. incinerator with a scrubber to be located in Onondaga, Michigan.

MINNESOTA	none
MISSISSIPPI	none
MISSOURI	none
MONTANA	none
NEBRASKA	none
NEVADA	none
NEW HAMPSHIRE	none

NEW JERSEY 1

Rollins Environmental Services
Bridgeport, New Jersey
609-467-3100

for details see Louisiana

NEW MEXICO none

NEW YORK There are no commercial incinerators, however there are 2 companies that burn hazardous waste for fuel.

Norlite Corp.
Cohoes, New York
518-235-0401
Mr. North, Plant Engineer

NEW YORK Norlite Corp.
rotary kiln
12-15,000 gal/day depending on BTU of fuel
waste solvents, paint thinners, alcohols
(limits on heavy metal concentration)

North East Solite aka Hudson Valley Aggregate
Mt. Marion, New York
914-246-2177
15-20,000 gal/day
waste oil, solvents

NOTE: Alpha-Portland Cement Co. in Jamesville, New York (315-469-5003) has a cement kiln that has burned hazardous waste in the past. They may burn hazardous waste in the future.

NORTH CAROLINA 1

Caldwell Systems, Inc.
Route 1, Mt. Herman Road
Hudson, North Carolina 28638
Charles Fushi
704-728-3251
liquid injection
1,800 lbs/hour (4 gal/min)
operate 24 hours/day, 5 days/week
polyester resins, waste oil, cleaning solvents,
furniture-making wastes
physically located in Lenor, N.C.
no air pollution controls

NORTH DAKOTA none

OHIO 1

Robert Ross and Sons, Inc.
394 Giles Road
Grafton, Ohio
216-748-2171

single chamber incinerator
16,000 lbs/hour, depending on BTU value
operate continuously; down time = 15%
industrial wastes from contaminated aqueous to flammable
replacement cost = $\$1.5 \times 10^6$
In the near future this Co. would like to install an incinerator in Coshocton County.

OKLAHOMA none, however, Petro, Inc. is contemplating building an incinerator in Muskogee, Ok.

OREGON none
PENNSYLVANIA none

RHODE ISLAND none

SOUTH CAROLINA 2

Abco Industries, Inc.
P.O. Box 335
Roebuck, South Carolina 29376
803-576-6945
Mr. Charlie Milford, Thermal Oxidation Div.

liquid injection
15,000 lbs/hour max.
operate continuously except for maintenance
solvents, some pesticides
incinerator cost = $\$.5 \times 10^6$, entire plant = $\$1 \times 10^6$

Industrial Chemical Co. aka Quality Drum
Rockhill, South Carolina
803-327-5276

500 gal/hour (12,000 gal/day max.)
continuous operation if enough volume
paint solvents, acetone

SOUTH DAKOTA none

TENNESSEE 2

Solid and Liquid Waste Disposal
P.O. Box 1101
Dyersburg, Tennessee 38024
901-285-8481
Mr. Jerry Ellis

Prenco liquid injection
125-135 gal/hour
operates continuously; down time = 2 days/month
90% of wastes are water and oil solutions, solvents
cost of incinerator = $123,000

TEXAS 2

Rollins Environmental Services
Houston (Deer Park), Texas
713-479-6001

for details see Louisiana

TEXAS

Sheridan Disposal Service, Inc.
Box 42
Hempstead, Texas 77445
713-826-3766

liquid injection
10,000 gal/day
hours of operation depend on amount of fuel available; for 11 months of last year, 350,000 gal/month
oily waste, cutting oils, cooling oils
designed and built by Mr. Sheridan

UTAH none
VERMONT none

VIRGINIA 1

Liquid Waste Disposal of Virginia
Richmond, Virginia
804-355-2563

700 gal/hour
operate 8-10 hours/day, 5 days/week
liquid wastes with a flash point (e.g. contaminated ink solvents)
cost of incinerator = $60,000

WASHINGTON none, however a pilot study was done recently by Chem-Nuclear of Bellvue, Washington. The report has not been released yet.

WEST VIRGINIA none

WISCONSIN none, however Waste Research & Reclamation Co., Inc. (Route 3; Eau Claire, Wisconsin, 54701; 715-834-9624) is trying to get a state license for their incinerator. They do not expect to open within the year.

WYOMING none

Umweltbundesamt
FG III 2.2

Annex VI

Bismarckplatz 1
1000 Berlin 33
(030) 89 03-1, Durchwahl -269 o.-421

Sonderabfallverbrennungsanlagen in der Bundesrepublik Deutschland

(aus Informationsschrift Abfallarten, Stand 1978)

Anlagenart	Standort	Betreiber	Stoffgruppen
BAYERN			
Verbrennungsanlage	Rother Str. 56 8540 Schwabach Tel. 09122/850 58/59	Zweckverband Sondermüllplätze Mittelfranken (SMM) Rother Str. 56 8540 Schwabach Tel. 09122/850 58/59	
Verbrennungsanlage	Uferstr. 10 8720 Schweinfurt Tel. 09721/844 58	Gesellschaft zur Beseitigung von Sondermüll in Bayern (GSB) Herzogstr. 60 8000 München 40 Tel. 089/33 10 53	feste und schlammförmige brennbare Sonderabfälle, hausmüllähnliche Industrie- und Gewerbeabfälle
Verbrennungsanlage	8076 Ebenhausen bei Ingolstadt Ldkr. Pfaffenhofen Tel. 08453/626/627	Gesellschaft zur Beseitigung von Sondermüll in Bayern (GSB) Herzogstr. 60 8000 München 40 Tel. 089/33 10 53	feste, schlammförmige und flüssige brennbare Sonderabfälle, hausmüllähnliche Industrie- und Gewerbeabfälle, feste Rückstände aus Shredderanlagen
HAMBURG			
Verbrennungsanlage	Borsigstr. 2 2000 Hamburg 74 Tel. 040/733 00 31	Kommanditgesellschaft AVG Abfallverbrennungsgesellschaft mbH & Co. Grimm 8 2000 Hamburg 11	feste, pastöse, flüssige Abfälle und Schlämme
Verbrennungsanlage	Peutestr. 57 2000 Hamburg 28 Tel. 040/78 70 27	Ascalia GmbH Fabrik chemisch-technischer Produkte Amelungstr. 2 2000 Hamburg 36 Tel. 040/35 13 66	halogenfreie Lösemittel
HESSEN			
Verbrennungsanlage	6081 Biebesheim Ldkr. Groß-Gerau	HAVG - Hessische Abfallverbrennungs-GmbH Industriegebiet 6081 Biebesheim Tel. 06258/60 61 (Tochtergesellschaft der Hess. Industriemüll GmbH)	Öl-Wasser-Gemische, Emulsionen aus der metallverarbeitenden Industrie, Ölschlämme, Feststoffe

NIEDERSACHSEN			
Verbrennungs-, Emulsionsspaltanlage	3250 Afferde Ldkr. Hameln-Pyrmont	Elektrizitätswerk Wesertal GmbH Bahnhofstr. 18-20 3250 Hameln Tel. 05151/10 81	Altöle und sonstige brennbare Flüssigkeiten der Gefahrklasse A III
Verbrennungs-, Neutralisations-, Entgiftungsanlage	Ldkr. Osnabrück	GSG - Gewässerschutz- und Städtereinigung GmbH Am Kanal 4550 Bramsche 3 Tel. 05461/34 21	pumpfähige Abfälle wie Genußmittelabfälle, Abfälle aus pflanzlichen und tierischen Ölen, Fetten und Wachsen, Abfälle von pharmazeutischen Erzeugnissen, Mineralöle sowie Emulsionen, Gemische und Schlämme von Mineralölprodukten, Lösemittel und Lösemittelgemische, Farben, Farbmittel und Lacke, Klebstoffe, Gummischlämme und -emulsionen, Chemikalienreste, Destillationsrückstände
NORDRHEIN-WESTFALEN			
Verbrennungsanlage	Hagen-Hohenlimburg RP Arnsberg	Fa. Bilstein & Co. Postfach 45 5800 Hagen-Hohenlimburg Tel. 02334/821	Mineralöle, Emulsionen und Gemische von Mineralölprodukten
Verbrennungsanlage (Hausmüll)	Iserlohn - Iserlohnerheide Märkischer Kreis RP Arnsberg	Märkischer Kreis Nebenstelle Postfach 37 5990 Altena Tel. 02352/20 01	Nahrungsmittelabfälle, Genußmittelabfälle, Abfälle aus pflanzlichen und tierischen Ölen, Schlämme mit und Raffinationsrückstände von pflanzlichen und tierischen Fettprodukten, Holzabfälle, Papier- und Pappeabfälle, sonstige Abfälle tierischen und pflanzlichen Ursprungs sowie von Veredlungsprodukten, sonstige feste mineralische Abfälle, Abfälle von pharmazeutischen Erzeugnissen, Mineralöle, Fette und Wachse aus Mineralöl, Mineralölschlämme, Rückstände aus Mineralölraffination, lösemittelhaltige Schlämme, Farbmittel und Anstrichmittel, Kunststoffschlämme und -emulsionen, Textilabfälle
Verbrennungsanlage	Bergkamen Kreis Unna RP Arnsberg	Fa. Schering AG Postfach 15 4619 Bergkamen Tel. 02307/191	Abfälle aus pflanzlichen und tierischen Ölen, Emulsionen, Gemische und Schlämme mit und Raffinationsrückstände von pflanzlichen und tierischen Fettprodukten, sonstige feste mineralische Abfälle, Abfälle von Pflanzenbehandlungs- und Schädlingsbekämpfungsmitteln, Abfälle von Körperpflegemitteln, Abfälle von pharmazeutischen Erzeugnissen, Mineralöle, Fette und Wachse aus Mineralöl, Emulsionen und Gemische aus Mineralölprodukten, Mineralölschlämme,

			Rückstände aus Mineralölraffination, sonstige Abfälle von Mineralölprodukten aus der Erdölverarbeitung und Kohleveredlung, halogenhaltige organische Lösemittel und Lösemittelgemische, halogenfreie organische Lösemittel und Lösungsmittelgemische, lösemittelhaltige Schlämme, Farbmittel und Anstrichmittel, Klebstoffe, Kitte, nicht ausgehärtete Harze, Laborabfälle und Chemikalienreste, sonstige Abfälle chemischer Umwandlungs- und Syntheseprodukte
Verbrennungsanlage	Krefeld-Uerdingen RP Düsseldorf	Bayer AG Werk Uerdingen Rheinuferstr. 4150 Krefeld-Uerdingen Tel. 02151/88 32 75	sonstige feste mineralische Abfälle, Abfälle von Pflanzenbehandlungs- und Schädlingsbekämpfungsmitteln, Abfälle von pharmazeutischen Erzeugnissen, Mineralöle, Fette und Wachse aus Mineralöl, Mineralölschlämme, halogenfreie organische Lösemittel und Lösungsmittelgemische, lösemittelhaltige Schlämme, Farbmittel und Anstrichmittel, nicht ausgehärtete Kunststoffabfälle, -formmassen und -komponenten, Laborabfälle und Chemikalienreste, Detergentien- und Waschmittelabfälle
Verbrennungsanlage	Niederkassel-Ranzel Rhein-Sieg-Kreis RP Köln	Fa. Widdig GmbH Markusstr. 5216 Niederkassel-Ranzel Tel. 02208/42 60	Nahrungsmittelabfälle, Genußmittelabfälle, Abfälle aus pflanzlichen und tierischen Ölen, Emulsionen, Gemische und Schlämme mit pflanzlichen und tierischen Fettprodukten, Holzabfälle, Abfälle aus der Zelluloseverarbeitung (ohne Chemikalien), Papier- und Pappeabfälle, sonstige Abfälle tierischen und pflanzlichen Ursprungs sowie von Veredlungsprodukten, sonstige feste mineralische Abfälle, Mineralöle, Textilabfälle
Verbrennungsanlage	Köln-Rondorf RP Köln	Rich. Buchen & Co. Postfach 50 18 60 5000 Köln-Sürth Tel. 02236/610 11	Emulsionen und Gemische mit pflanzlichen und tierischen Fettprodukten, sonstige feste mineralische Abfälle, Mineralöle, Fette und Wachse aus Mineralöl, Emulsionen und Gemische von Mineralölprodukten, Mineralölschlämme, halogenhaltige organische Lösemittel und Lösemittelgemische
Verbrennungsanlage	Leverkusen-Bürrig RP Köln	Bayer AG 5090 Leverkusen Tel. 02172/301	Holzabfälle, Abfälle aus der Zelluloseverarbeitung (ohne Chemikalien), Papier- und Pappeabfälle, sonstige feste mineralische Abfälle, Abfälle von Pflanzenbehandlungs- und Schädlingsbekämpfungsmitteln, Abfälle von pharmazeutischen Erzeugnissen, Mineralöle, Fette und Wachse aus

			Mineralöl, Emulsionen und Gemische von Mineralölprodukten, Mineralölschlämme, halogenhaltige und halogenfreie organische Lösemittel und Lösemittelgemische, lösemittelhaltige Schlämme, Farbmittel und Anstrichmittel, Klebstoffe, Kitte, nicht ausgehärtete Harze, Kunststoffschlämme und -emulsionen, Textilabfälle, Laborabfälle und Chemikalienreste, Detergentien- und Waschmittelabfälle
Verbrennungsanlage	Köln-Niehl RP Köln	Ford-Werke AG Ottoplatz 2 5000 Köln 21 Tel. 0221/825 54 58	sonstige feste mineralische Abfälle, Abfälle von pharmazeutischen Erzeugnissen, Mineralöle, Fette und Wachse aus Mineralöl, Emulsionen und Gemische von Mineralölprodukten, Mineralölschlämme, halogenhaltige organische Lösemittel und Lösemittelgemische, lösemittelhaltige Schlämme, Farbmittel und Anstrichmittel, Klebstoffe, Kitte, nicht ausgehärtete Harze
Verbrennungsanlage	Wesseling Erftkreis RP Köln	Union Rheinische Braunkohlenkraftstoff AG Ludwigshafenstr. 5047 Wesseling Tel. 02236/791	Nahrungsmittelabfälle, Papier- und Pappeabfälle, sonstige feste mineralische Abfälle, Mineralöle, Fette und Wachse aus Mineralöl, Emulsionen und Gemische von Mineralölprodukten, Mineralölschlämme, Rückstände aus Mineralölraffination, sonstige Abfälle von Mineralölprodukten aus der Erdölverarbeitung und Kohleveredlung
Verbrennungsanlage	Aachen-Laurensberg RP Köln	Rheinisch Westfälische Technische Hochschule Aachen Templergraben 55 5100 Aachen Tel. 0241/421	Holzabfälle, Papier- und Pappeabfälle, Abfälle von Pflanzenbehandlungs- und Schädlingsbekämpfungsmitteln, Abfälle von pharmazeutischen Erzeugnissen, Mineralöle, Fette und Wachse aus Mineralöl, Emulsionen und Gemische von Mineralölprodukten, Mineralölschlämme, Rückstände aus Mineralölraffination, sonstige Abfälle von Mineralölprodukten aus der Erdölverarbeitung und Kohleveredlung, halogenhaltige organische Lösemittel und Lösemittelgemische, lösemittelhaltige Schlämme, Farbmittel und Anstrichmittel, Klebstoffe, Kitte, nicht ausgehärtete Harze, Kunststoffschlämme und -emulsionen, Gummischlämme und -emulsionen, Laborabfälle und Chemikalienreste

Verbrennungsanlage	**Münster** **RP Münster**	**Glasurit-Werke** **Max-Winkelmannstr. 37** **4400 Münster** **Tel. 02501/141**	**Holzabfälle, Papier- und Pappeabfälle, sonstige feste mineralische Abfälle, NE-Metallabfälle, Säuren, Laugen, Mineralöle, Fette und Wachse aus Mineralöl, Emulsionen und Gemische von Mineralölprodukten, Mineralölschlämme, Rückstände aus Mineralölraffination, sonstige Abfälle von Mineralölprodukten aus der Erdölverarbeitung und Kohleveredlung, halogenhaltige und halogenfreie organische Lösemittel und Lösungsmittelgemische, lösemittelhaltige Schlämme, Farbmittel und Anstrichmittel, Klebstoffe, Kitte, nicht ausgehärtete Harze, Gummischlämme und -emulsionen, Textilabfälle, Laborabfälle und Chemikalienreste**
Verbrennungsanlage	**Marl** **Kreis Recklinghausen** **RP Münster**	**Chemische Werke Hüls AG** **Postfach 11 80** **4370 Marl** **Tel. 02365/491**	Holzabfälle, Papier- und Pappeabfälle, sonstige feste mineralische Abfälle, Mineralöle, Fette und Wachse aus Mineralöl, Emulsionen und Gemische von Mineralölprodukten, Mineralölschlämme, sonstige Abfälle von Mineralölprodukten aus der Erdölverarbeitung und Kohleveredlung, halogenfreie organische Lösemittel und Lösungsmittelgemische, lösemittelhaltige Schlämme, Farbmittel und Anstrichmittel, Klebstoffe, Kitte, nicht ausgehärtete Harze, nicht ausgehärtete Kunststoffabfälle, -formmassen und -komponenten, Kunststoffschlämme und -emulsionen, Gummischlämme und -emulsionen, Textilabfälle, Laborabfälle und Chemikalienreste, Detergentien- und Waschmittelabfälle
Verbrennungsanlage	Ibbenbüren Kreis Steinfurt RP Münster	CSC-Chemie Postfach 4530 Ibbenbüren Tel. 05459/70 21	halogenfreie organische Lösemittel und Lösungsmittelgemische